CHALMERS

Reducing space requirements in a production system

- Decision support based on Discrete Event Simulation

Master of Science Thesis in the Master Degree Programme, Production Engineering

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Preface

This report is the result of a master thesis project conducted at a Swedish production company between January and May 2010. The master thesis project has been the final compulsory part in the master's degree programme Production Engineering provided by the department of Product and Production Development at Chalmers University of Technology.

We are very thankful towards The Company for providing an opportunity to perform our master thesis at their production facility. The project has provided us with a chance to use knowledge gained throughout our studies and run a sharp project at a real production facility. The help gained from the company both concerning the project as well as administrative tasks have been very useful. We would especially like to thank our tutor at the Company and other people that have helped us during this project.

We would also like to thank our tutor at the department of Product and Production Development, Anders Skoogh, for all the help received throughout this project.

Göteborg 3 of June 2010

Nils Andersson Henrik Skoogh

Abstract

A competitive market has driven companies to offer many different types of products in order to satisfy more customers and increase production. More product types have consequentially required new ways of handling material and increase flexibility in production. This master's thesis work has been focused on this problem in a company that is in need of expansions on several different areas. Unfortunately there is no available space for growth, meaning the company needs to reduce the requirements of space in the current production system.

The aim of the master thesis is to provide decision support for the company by finding different feasible suggestions regarding configuration of current production system. The suggestions must meet the capacity and space required by the company. The company has problem with overstocking of components and semi-finished goods and want to address these problems in order to reduce throughput times and WIP. Discrete event simulation (DES) has been used to evaluate different scenarios that were generated with theory as basis. DES has provided the best configuration for each scenario as well as performance measurements used to compare and evaluate the suggestions.

The scenario that resulted in least requirements of space in the production system was based on a new way of categorizing product types. Instead of sorting products of different types the suggestion is to sort them according to excepted time to be assembled which can reduce the required space with 48 %. The suggestion is not affected of different variants and has great potential to be improved by further reducing lead time and WIP.

Unavailable data has caused difficulties in modeling and validating the simulation model. The Company is recommended to improve machining processes with for example logging; OEE, Cycle times, setup times, time for exchange of tools, maintenance and working procedures etc. These should be properly investigated, documented and **improved**. This will also enable problems to reach the surface which will ease the work with continuous improvements and make it possible to reduce lead time and space requirements even further.

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1 Introduction

The introduction describes the background, purpose, aim, problem formulation and delimitation of the master thesis. The company's name where the master thesis project was carried out cannot be revealed due to secrecy regulations and will in the report be mentioned as "The Company". A short description of the production facilities is also included in this chapter.

1.1 Background

On a competitive market, a company can gain advantages by offering the best products to the customer. It is the customer who sets the demand on the products and the companies must meet these demand. The customers want the products to be customized for their special needs which in many cases will result in one unique part for each customer. If the company wants to scale up the production they need to offer more variants in order to satisfy more customers. More variants in the production will also require new ways of handling material that can cope with all the variants.

This problem has been the main focus in this project. The Company produces a product made mainly out of steel which involves both machining and assembly. The production site holds four divisions where one concerns manufacturing of the product. The company has lately been forced to perform radical changes in the production facilities in order to meet future demands. All four divisions in the production facility want to expand their available space. Desires that are not possible to meet for all parts without expanding the production facility. Therefore the already available space is in need to be revised in order to investigate the possibilities to increase the space utilization and to make room for future expansions.

The layout of the current production system is quite old and there are some issues regarding material handling. The major changes in the production require a thorough investigation of production and logistic matters in order to meet cost and quality goals. There are different ideas and suggestions about the layout and configuration of the future production system in the organization. A simulation will be carried out in order to provide decision support to the project team working on the implementation of a new production system. A curiosity in the organization about the pros and cons concerning discrete event simulation has been a factor when choosing simulation as a means of evaluation. The results of this project will be valuable when decisions about dedication of available space between the different divisions inside the production site are made.

1.2 Purpose

Future increase in demand has required the company to take action regarding expanding their production system. The available space, at the division responsible for producing the product, needs to be revised in order to make room for future expansions. The purpose is to determine how the production system can be configured in order to reduce the amount of space that is required for the production system to run and remain a capacity stated by the company.

1.3 Aim

The aim of the master thesis is to provide decision support for the company when improving available space in the production system. This will be done by finding different feasible suggestions regarding configuration of current production system. These suggestions will be evaluated with DES and meet the capacity and space requirements that have been stated by the company. One of the suggestions will be presented as the best solution for implementation.

1.4 Problem formulation

In order to meet the future demands the company has to make improvements to the production system regarding its space utilization. Increasing the capacity will require expansions that are not possible in the current production system. The current layout which was set for about 15 years ago has resulted in overstocking of components and semi-finished goods. The company wants to address these matters if possible, and reduce the throughput times and WIP. Since the production facility contains other divisions that are also interested in expanding, the production space for the product must be kept at a minimum.

The main question that this work will answer is:

- MQ: How can the production system be configured in order to meet the requirements on capacity and space stated by the company?

The following sub-questions will facilitate answering the main question:

- Q1: How much space can be freed in the current production system?
- Q2: What are the critical parameters that affect the capacity and space?

1.5 Delimitations

The delimitations were first set up with intention to have no effects on the results, but this has not been possible to achieve in order to finish the project in reasonable time. The delimitations need to be taken into consideration before any suggestions are transferred into reality.

- Materials that are shipped to the factory are expected to always be available.
- Quality defects will not be taken into consideration in the model.
- Setups involving changes of fixtures are not considered in the model.
- Only variants of carriers that have been processed from January to April 2010 are considered in the model.
- Carriers machined for shipping unassembled are not considered in the model.
- Truck transports or kanban calls are expected to be processed within two hours from when a call has been initiated.

1.6 Factory description

In order to produce the product both assembly and machining are required in the factory. Many of the machining processes have also been outsourced and machined components are delivered to the factory ready for assembly but all of the assembly and pre-assembly are made within the factory.

The production of the product is divided into two main blocks in the factory; assembly A and machining B. The blocks are situated in the same building but in two separated factory halls. The assembly consists mainly out of manual work but some stations are fully automated. The machining block has a high level of automation and is divided into three smaller blocks. Manual work only consists of monitoring and feeding machines and robot cells with raw material. Raw materials are stored in central storage while machined materials are stored at assembly or machining. A simplified illustration of the factory layout can be seen in Figure 1.

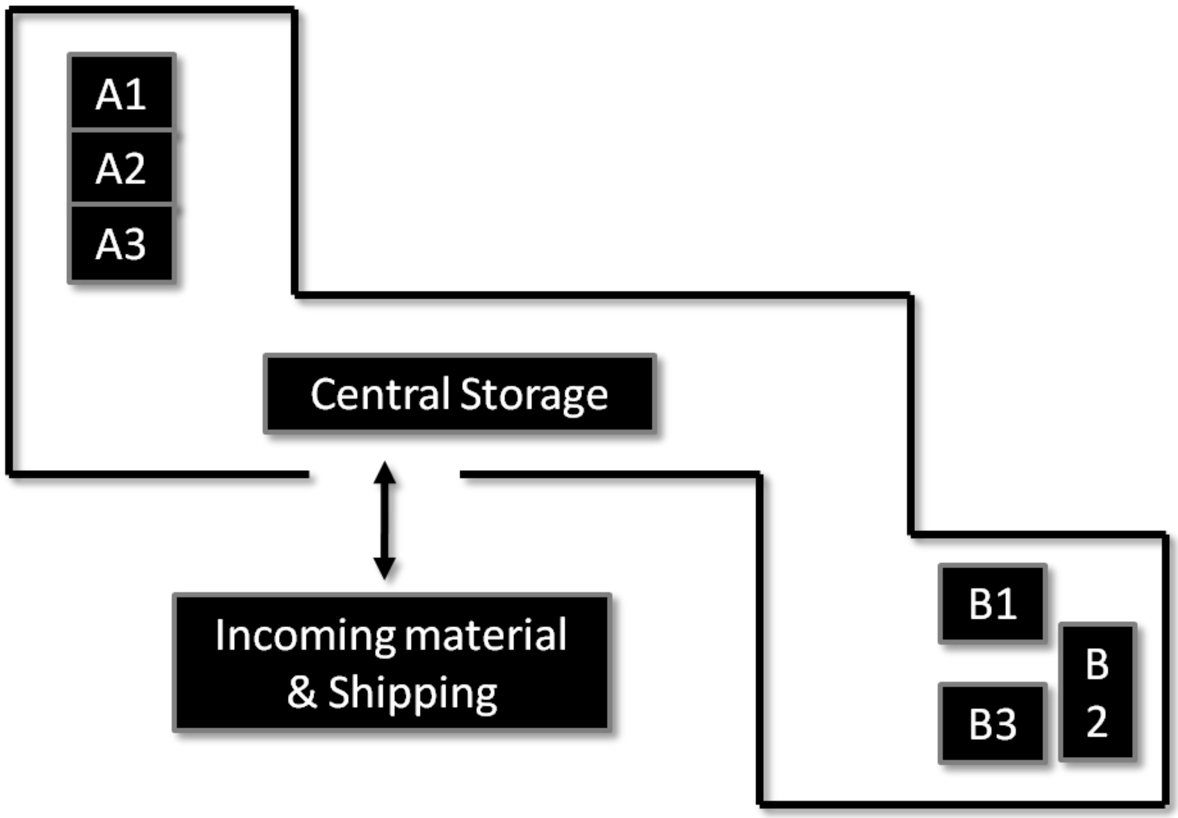

Figure 1 - Factory layout

The assembly consists of three smaller blocks with two pre-assembly blocks A1 and A2 and one final assembly block A3.

The mechanism to the product is assembled in block A1. The assembly line consists of four manual assembly stations and an automated process between station 2 and 3.

The mechanism from A1 is mounted onto component 2 in block A2 and is passed through a gluing process. After the gluing process the product needs to dry for a time. The gluing process is fully automated while the mounting onto the component 1 is performed manually.

In block A3 the final product is assembled and packed. The assembly line consists of 10 stations and one packaging station. Three of the stations are fully automated whereas the other stations are manual. One of the automated stations consists of a robot cell. The line is driven by an accumulating conveyor with products on pallets. The conveyors allow buffers of 2-4 pallets between the stations.

The lever is machined in block B1 by an automated machine that needs to be fed and emptied manually. The machine can take eight parts at a time but cannot be fed or emptied while running.

In block B2 there are five machines available for machining the carrier. The five machines are divided into two robot cells with two and three machines fed by one robot in each cell. Each machine contains two fixtures which hold two carriers. One fixture at a time is processed in each machine. The other fixture can be loaded in advance enabling the machines to run without interruptions. The machines are dedicated to special variants of carriers but each machine can take any type of carriers if a setup is performed. Machined carriers are always processed in batches of 28.

The crossbar is machined in block B3 by an automated machine which takes six crossbars at a time. The machine is fed by a robot making the whole process of machining crossbar automated.

2 Method

The methodology for modeling a system in the project follows Bank's model (Banks, et al. 2005) with minor modifications in order to be better adapted to this project. The steps are explained in this chapter together with other methodologies used during this project.

2.1 Discrete event simulation (DES)

DES has been used in order to create a virtual representation of the production system at the company. A basic DES-model contains representations of different resources and queues such as machines, manual workstations and conveyor belts. In a detailed model it is possible to model operators, forklifts and shifts along with many other things. These entities are then linked together to form a model. (Banks, et al. 2005)

Using DES provides a possibility to experiment with a system without any affect on the real system. Other advantages of DES are:

1. Hypotheses about how or why certain phenomena occur can be tested
2. Long periods of time can be simulated in a fraction of the real time
3. Critical parameters for the system performance can be obtained
4. Bottleneck analysis can be performed in order to determine where improvements has to be made in order to improve the system performance
5. "What if" questions can be answered

Disadvantages of DES are:

1. Model building requires special training and is learned over time and through experience.
2. Two models of the same system created by different modeler does not necessary look and operate the same way.
3. Simulation results can be difficult to interpret, whether the results are an effect of system interrelationship or of randomness.
4. Time consumption is generally high when it comes to simulation as well as the cost. If the resources both concerning time and money are short the result could be that the simulation model and analysis are not sufficient.
5. Simulation of systems that is simple enough for easier and cheaper ways of analysis.

(Banks, et al. 2005)

2.2 Bank's model

There have been several attempts to create a standardized way of conducting a DES project. Although many are working in a similar fashion no standard is present. One of the more accepted models is Banks model which is illustrated by a flowchart over how a DES project should be conducted and detailed descriptions. This master thesis follows the model in order to keep a structured way of working. The flowchart is shown in Figure 2.

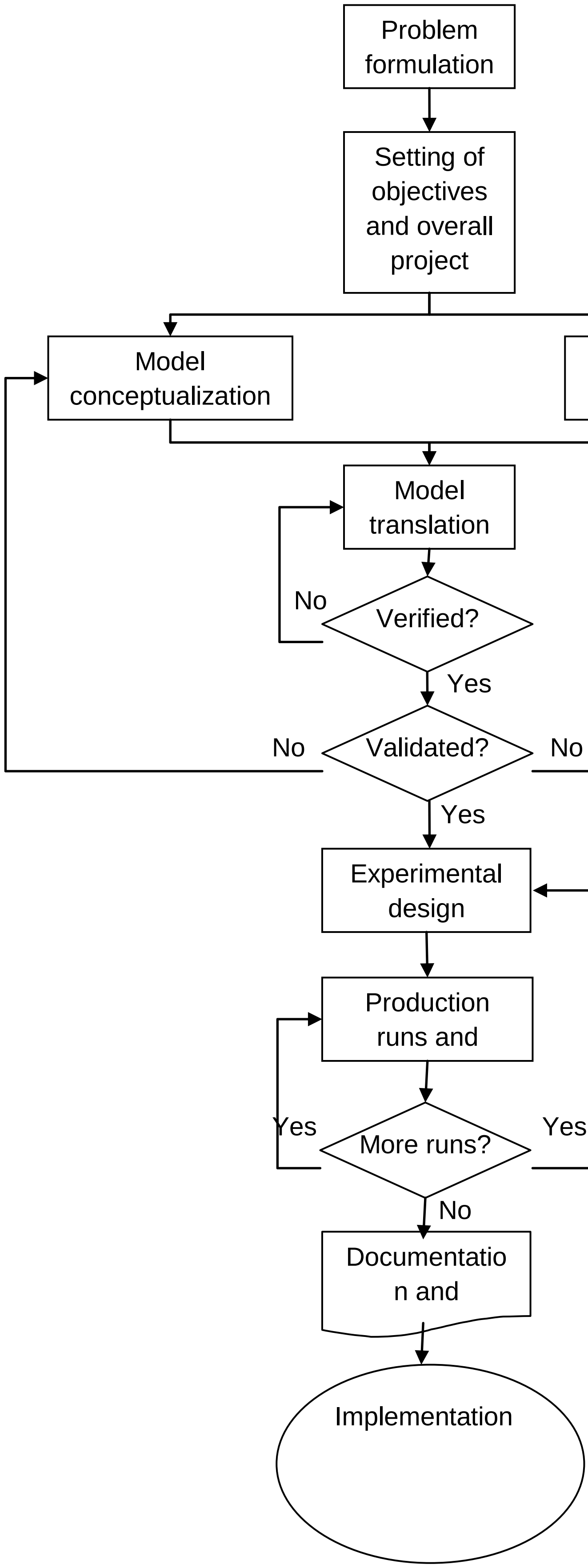

Figure 2 - Banks model

2.3 Problem formulation

The importance of a good problem formulation cannot be stressed enough since the success of the project often depends on a common view of what should be accomplished and how. The problem formulation can come from different positions such as the analyst or the policymakers but should always be agreed upon by all parts. (Banks, et al. 2005)

In order to produce a good problem formulation for this project, consensus between the different stakeholders of the project had to be reached. In order to achieve that, discussions were held between the analysts and the company as well as between the analysts and the tutor at Chalmers. In order to finalize the problem formulation a meeting was set up with all three parts where the problem formulation was set. The problem formulation was later on in the project revised in order to increase the depth of the more important parts.

2.4 Setting objectives and project plan

When the problem has been formulated it is necessary to more clearly state which objectives the project has, and also create a project plan. The project plan should contain necessary information regarding time frame, the different tasks that shall be done and other relevant information for the project. (Banks, et al. 2005)

A project plan was constructed for the project, consisting of background, purpose, aim, problem formulation, project focus, delimitations and basic theory. The project plan was agreed upon in the same manner as the problem formulation.

One of the more important factors concerning the objectives was which results that the project should generate and which input and output parameters that were going to be used. As with the problem formulation, the objectives were revised at a later point in order to increase the depth of the more important parts.

2.5 Conceptual model

Building a conceptual model is essential for how the DES model will operate. During the model conceptualization step, the characteristics of the system are decided. At this state it is determined how detailed and accurate the model should be when the programming part is over. It is not always necessary to aim for as detailed as possible, more often it is quite the opposite due to the complexity. It is generally stated that when a conceptual model is constructed it is beneficial to start on a low level considering the detail of the model and then make the model more and more complex until the desired level of complexity is reached. Apart from the previously stated benefits of the conceptual model it is also an important tool for projects where more than one person is working on the same model more or less simultaneously. In that case it works as a common ground in order to ensure unity in the modeling phase. (Banks, et al. 2005)

A conceptual model was constructed early in the project in order to represent how the production system was viewed and which parts that were going to be included in the model. A conceptual model consists of a graphic representation of machines, queues, logistic routes, warehouses and order points as well as more detailed information concerning the production system.

2.6 Data collection

Since data collection is one of the most important parts of a DES project a lot of time was put into gathering and analyzing data concerning the production system. Almost 30% of the total time in a DES project concerns input data which is due to the fact that bad input data generates bad output data. (Skoogh and Johansson 2008)

Gathering data can be a difficult task depending on the availability of the data. There are three main types of input data according to Robinson and Bhatia (1995), these are:

- Available data
- Collectable data
- Data which is neither available nor collectable

Since available data is the most preferable type this type of data was gathered first. Available data can be extracted from different sources, such as data logs, production managers and already performed time studies. In case there are some areas which are not covered by available data the second most preferable type is collectable data. Collectable data consists of data that can be gathered manually by for example time studies or video recordings. This type is of course more time demanding but has the advantage that its validity is easier to determine. The last of the three types are data which is neither available nor collectable. This type of data must be estimated which can be done by for example interviews or benchmarking. (Robinson and Bhatia 1995)

The collection of data is only the first step of feeding the model with accurate data. In most cases the data that has been gathered must be processed by the simulation engineer in order make it useable for creating statistical representations, which then can be used in the simulation. There are numerous softwares, both standalone and integrated in simulation software, that can be used to create these representations. In this project AutoFit has been used which is integrated in the simulation software Enterprise Dynamics.

2.6.1 Order arrivals

The order arrivals used in this project were generated from the traceability which the company provided. The traceability shows when a product leaves the final assembly and which parts that are included in the final product. This data were then processed in order to create input to the model in the form of order arrivals. Microsoft Excel was used to create a spreadsheet which constructed the desired data.

Later into the project the data were manipulated further in order to reach the capacity stated by the company. The time span that was used consisted of the eight weeks during 2010 with the highest output. The manipulation consisted of scaling each and every order ensuring that the total would correspond to the stated capacity. An increased demand in real life does not have to change the order arrivals in the way suggested here, but since it is impossible to know how the future demand will be, the easiest method was selected.

2.6.2 Cycle times, set up times and packaging

Cycle times and set up times for both machines and manual operations were gathered mostly by time studies and estimations. Only in a few cases were there reliable data which could be used as input to the model. A time study was conducted where data that had to be gathered were obtained. The data received from the time study concerned cycle times for the final assembly as well as the pre assembly. In some cases the amount of variants meant that it was impossible to get any measurements. This since some parts was not produced during the projects duration. In those cases estimations were made with the help of production engineers and operators. Packaging instructions telling how many complete products should be packed together to customer were gathered from the unloading division.

2.6.3 Breakdowns

Gathering data concerning breakdowns proved to be a challenge since documentation and logging were scarce. In some cases OEE measurements were available which could be processed into data that could be used. This was mostly true for assembly and pre-assembly while false for machining. Data concerning breakdowns in machining had to be estimated, which were made with help from production engineers as well as operators. In some cases breakdowns concerning machining of carrier were disregarded. (Williams 1994)

2.7 Modeling

Modeling the system means transforming the conceptual model into a simulation model. There is numerous different software which all have different characteristics and the one best suited for a task changes depending on the tasks characteristics and which persons are involved in the project. (Banks, et al. 2005) During the project Enterprise Dynamics has been used to program the system behavior. The software uses a special script called 4D script. Since none of the analysts had used it before familiarization were very important at the early stages.

Since the simulation software contained a merge function it was possible to work with two different models. In the beginning the modeling tasks were more or less equally divided in order to work at double speed. After merging the two models simultaneous modeling has been limited. This has meant that whilst modeling has been perform by one analyst the other has had to do other tasks. It has, however, been possible to perform runs on multiple computers which have been important in terms of run time when performing analysis runs.

2.8 Verification

Verification concerns the logic of the model and whether it represents the conceptual model in an adequate way. Verifying a model is a continuous process which takes place during the coding of the model. This way of working has been adapted throughout this project. Performing the verification of a model can be hard if the model is to complex and it is important to know that higher complexity of a model often leads to higher amount of debugging. (Banks, et al. 2005)

Verification is often done by means of common sense instead of tools, which puts high demands on accuracy for the analysts (Banks, et al. 2005). In this project the verification has been done mostly by common sense used together with the conceptual model. Other types of verification that has been used are examination of the outputs and their behavior as well as visual verification.

2.9 Validation

Validation means calibrating the model in order to get accurate output from the model. The process of validation can be described as comparing the models output with the “output” of the real system. When comparing the model with reality it provides information on whether the model has to be changed in order to fit more accurately to the reality. The process of validation is of an iterative nature which means that scenarios are run several times and the results are evaluated and the model is changed in accordance with the results. There are almost unlimited amount of parameters that can be measured when trying to validate a model. The choice is mainly influenced on what types of data that are available from the real system and the quality of the data. (Banks, et al. 2005)

In this project validation has been made mainly by comparing OEE from the real system with the model. The reason for this has been the amount of available data for the parts that needed to be validated. Validation has been made for the machining, as well as the assembly and the pre-assembly. Since the input to the system is on a weekly basis it follows that the output per week is equal for the model and reality. This means that the validation has to be complemented with a validation on a daily basis in order to see how the model behaves when not constricted by the input data.

In order to evaluate the systems validity on a daily basis plots were constructed for pre-assembly and assembly which could be visually validated. For machining, interviews were made in order to establish that the system had a reasonable maximum output. This is method called face validity described by Sargent (2007).

When OEE data were scarce only the output has been used for validation. In order to provide better validation for parts with scarce OEE data, operators and engineers were asked about the validity of the results. The results from comparison of output data, together with the information gained from operators and engineers provided a certain level of validity. In order to further establish the validity of the system a sensitivity analysis were conducted.

If the difference between the model and the reality is less than ±2% the system is considered to be validated. If the difference is larger than ±2% more analysis has to be done in order to ensure validity. This is not a stated in theory rather a value constructed for this specific project.

2.10 Sensitivity analysis

Sensitivity analysis concerns varying variables which are considered sensitive in respect to the models total performance. A sensitivity analysis should be performed in order to ensure that slight variations in variables do not change the results in a drastic matter. There are several ways to approach a sensitivity analysis, one example being the brute force approach. Brute force approach means that the variables are changed and a new run of the model is made thus providing new results. The brute force approach is useful when it is possible to perform runs in an efficient manner, i.e. the model is of less complexity. (Chinneck 2000)

For this project the brute force approach have been chosen. In order to find the amount of variation the system can handle an iterative approach has been used. Four variables have been changed during the process in order to evaluate the system's performance. The variables that were changed are unknown cycle times, time between tool change, change of tools duration and set-up duration.

The first approach concerned varying all variables simultaneously in order to find a maximum variation for all variables. The information gathered from these runs was then used to evaluate the most significant variable and later the least significant variables.

To conduct an iterative experiment a starting value were chosen. If the run generated no faults the starting value were increased by 10 percentage points and if faults were generated the starting value were decreased by 10 percentage points. When a successful run were located next to a run containing faults, a value between the two points were evaluated. In this manner a result could be obtained with a resolution of 5%.

2.11 Generate scenarios for carrier

The carrier is the part that requires most pallet slots at assembly and has been one target of focus when approaching space problems in the project. The simulation model has been used to investigate four different scenarios that have different suggestion of how machining and logistics, concerning the carrier, can be handled. The scenarios have been generated with theory as basis and also from ideas among stakeholders at the company.

2.12 Evaluation of scenarios for carrier

Different performance measurements were needed to be elaborated in order to determine which scenario that would gain most benefits for implementation. During the experimentation many single runs were performed on the different scenarios with different input data in order to gain the best results from each scenario.

2.12.1 Performance measurements

The inactive time were measured in the three different machines for machining of carriers. The inactive time were defined as the time when the machine was idle and there were no material available that could be processed in that particular machine and the whole cell wasn´t blocked due to set ups. From the measured inactive time the productivity could be calculated. Each time the machines for carrier required a set up due to new raw material this was recorded. The work in process (WIP, see section 3.13) were measured from when a pallet of carrier were allowed to enter the robot cell at machining until it left the packaging station at assembly.

Two types of errors were reported and monitored in the simulation model. The first error is if an operator fails to retrieve material at assembly because of material is missing at a warehouse. The second error is if transportation of material is in progress from machining to assembly but there is no available pallet slot.

2.12.2 Experimentation with each scenario

For each scenario single runs were made at an initial state which recorded data concerning the sizes of the different warehouses. A single run would be considered failed and would be rerun with new input data if an error occurred. From each single run the maximum usage of each warehouse could be determined which gave adequate indication of what could be reasonable input data for a multi-run simulation. All results from the scenarios are based on multi-simulation consisting of five runs with the same input data. Mean values of the output data from the five runs are used to evaluate the different scenarios.

2.13 Generate suggestions for material not machined in-house

The parts considered in this section contain component 1, component 2 and component 3. These parts are not machined in-house and need space in the warehouse that is being configured. There are other parts as well but they have not been considered mainly due to small requirements on space or storage elsewhere.

The suggestions for material which are not machined in-house were generated through two different approaches. The first approach was generated with continuous improvement in mind, and aims to improve the current situation by modifying the levels according to kanban principles. Formula 2, concerning the configuration of a kanban system, were used to get a starting point. The formula provides information concerning using one kanban card per pallet, and in order to evaluate a system with two kanban cards per pallet a modified material requirements planning (MRP) were used.

When configuring the system a worst case scenario has been designed, which in this case means that one product has been assembled for a whole day. This means a demand of 270 parts per day and a demand rate of one part per 1, 2 minutes. The demand rate is higher than the average which is one part per 1,6 min (daily demand/production time) but lower than the specified cycle time which is 1min. In addition there is a safety level of two hours present which corresponds to the time it takes for central storage to replenish material after a call.

The second approach was designed with Monden's theory in mind. Monden's theory states that in a production system with many variants and an uneven turnover of material a kanban system has drawbacks which are presented in section 3.7. In order to handle this variation of demand for each part a system with daily replenishment was constructed. The scenario has been influenced by material planning with a periodic ordering system as well as a generic kanban approach.

Since the demand for each part is not equal to the amount of material in each pallet, there are often pallets with left over material present in the warehouse. This has to be taken into account when designing the system and a formula was constructed to account for it which can be seen in Formula 1. The formula contains the amount of variants (v), the demand (d) and amount of parts in one pallet (p). In some cases variants have different amount of parts in the pallets which has lead to a worst case scenario approach of choosing the least amount.

$$n = v + (v - 1) + \frac{d - (2v - 1)}{p}$$

Formula 1 - Formula for determining amount of slots for daily replenishment scenario

The first part of the formula accounts for one pallet with leftovers per variant. If the amount of leftover material is one in each pallet and the demand for all variants, except one, being two all variants needs one more pallet which is accounted for in the next part of the formula. The final part of the formula accounts for the remaining demand divided by the amount of parts in a pallet. The numerator shows the amount of parts already accounted for, subtracted from the total demand.

2.14 Evaluation of suggestions for material not machined in-house

In order to evaluate the first scenario generated for materials that are not machined in-house a modified version of Material Requirements Planning (MRP) are used which were to show when a shortage of parts were present. The MRP were modified to match a discrete event system which means that the time row is not linear. Instead the events that influence the MRP generate the time. This leads to the MRP looking quite different but requiring fewer entries thus keeping only the important information.

The second scenario was evaluated by, in first hand, single runs in the simulation model. The formula stated in the previous chapter, provided a starting point and from there single simulation runs were made in order to see whether faults occurred. If a fault was detected a new single run was conducted with modified parameters. This process was iterated until the best possible configuration was achieved. In order to ensure the validity of the results, multiple runs (five) were conducted on the configuration that were achieved. If a fault was detected new multiple runs were conducted. This process was iterated until satisfactory results were achieved.

2.15 Identifying critical parameters

In order to provide information, which the Company can benefit from in the future, the critical parameters concerning space has been identified in the project. Critical parameters have been identified through analysis of the simulation model as well as through common sense while getting a deeper insight in how the production system works. The process of identifying critical parameters has been continuous and stretched throughout the project.

3 Theory

In this chapter central theories concerning this project are presented. The theories presented are used in order to further establish the results of the project and its validity. Theories are presented in alphabetical order.

3.1 Cycles in time study

When time studies are to be performed there are some rules and guidelines about how many measurements that needs to be performed in order to gain accurate input data. If the same number of measurements were to be made on different cycle times, longer cycle times would require more effort to measure. The numbers of cycles that can be studied form an economic standpoint. General Electric Company has established Table 1 as an approximate guide to the number of cycles to observe. More accurate number can be established by using statistical method. (Freivalds och Niebel 2009)

Table 1 - Recommended number of observation cycles

Cycle time (min)	Recommended number of cycles
0,10	200
0,25	100
0,50	60
0,75	40
1,00	30
2,00	20
2,00-5,00	15
5,00-10,00	10
10,00-20,00	8
20,00-40,00	5
40,00-above	3

3.2 Dedications versus randomized pallet slots

In the book Facilities Planning (Tompkins, et al. 1996) an example is described where storage is designed for six different products. Dedicated slots will require a warehouse with the size equal to the sum of individual maximum inventory levels, whereas a randomized warehouse will only require the size equal to the maximum of the aggregated inventory level. A similar example compared to the example by Tomkins et al is described below.

Five different types of a product are delivered to a warehouse once a week according to Table 2. By summing the inventory levels for the six types of carriers the aggregated inventory level is obtained. A dedicated slot warehouse would require a capacity of 42 whereas a randomized warehouse would require only 28 slots. A dedicated warehouse will always require more pallet slots compared to a randomized warehouse.

Table 2 - Example for dedicated versus randomized slots

	Product type					
Week	**1**	**2**	**3**	**4**	**5**	**Aggregate**
1	2	4	2	4	3	15
2	9	3	6	4	2	24
3	3	3	4	10	2	22
4	9	5	3	2	3	22
5	2	7	1	6	1	17
6	3	3	3	4	9	22
7	3	2	7	4	3	19
8	2	3	3	2	3	13
9	7	4	6	9	2	28
10	3	4	7	1	3	18
Maximum	9	7	7	10	9	

3.3 Material requirements planning

Material requirements planning (MRP) is a material planning method that is based on points in time for scheduling new deliveries being determined through the calculation of when further requirement of materials arise. A MRP consists of five different types of information which are time, requirement, stock on hand, planned order delivery and planned order start. MRP is usually used in order to see when a new order has to be released in order to prevent a shortage of parts. In an MRP a planning horizon is present which determine how far the planning can be made. MRP is generally considered a complex way of planning the production which means that the difficulty increases. (Jonsson and Mattson 2009)

3.4 OEE

Overall Equipment Efficiency (OEE) is a set of metrics that bring focus to key performance measurements in a production environment. In order to calculate OEE measurement for availability, performance and quality are multiplied. Availability is achieved by calculating the available production time divided by the scheduled production time. Performance is achieved by calculating the actual rate of production divided by the standard rate of production. Quality is achieved by calculating good units divided by started units. (Capstone Metrics LLC 2008)

OEE is a good way of measuring the performance of a production system and visualize the current and previous states as well as improvements. Using OEE in a reasonable way has positive effects such as improved profitability, increased customer satisfaction and the fact that it serves as a continuous improvement driver. (Capstone Metrics LLC 2008)

3.5 Periodic ordering system

A periodic ordering system means a material planning method which at certain time intervals compares the current stock with a target level and initiates a replenishment of the difference. Using a periodic ordering system is especially beneficial when several items are produced by the same supplier. In that case it is preferable if ordering and transportation of all different parts can be handled at the same time since this will require less ordering costs as well as transportation costs. A periodic ordering system is often used for finished goods stock as well as for goods with independent demand and frequent requirements. (Jonsson and Mattson 2009)

3.6 Productivity measurements

Productivity is a way to measure the efficiency for a process. Productivity is defined as output divided by input. The measurement of both output and input can vary depending on which process is being analyzed. (Card 2006) In this project productivity has been defined as the amount of production time that is utilized divided by the total available time. This measurement will show how much time that is not being used by a process. If improvements are made it is possible to utilize the idle time and thus increasing productivity and most likely the output.

3.7 Pull system / Kanban

"Material planning is of the pull type if manufacturing and materials movement only takes place on the initiative of and authorized by the consuming unit in the flow of materials" (Jonsson and Mattson 2009).

A pull system aims to create a smooth flow of materials through a production system without requiring much inventory, work in process and information communication. The basic principle of a kanban system is that a kanban card is released when a pallet becomes empty in the consuming unit thus allowing the supplying unit to replenish the material. To determine the amount of kanban cards that should be present in a system Formula 2 can be used, where n is number of kanbans, D is demand, L is lead time, α is a safety factor and a is the capacity of a standard pallet:

$$n = \frac{D * L * (1+\propto)}{a}$$

Formula 2 - Formula for determining the amount of kanban cards needed.

(Jonsson and Mattson 2009)

In order to achieve a successful kanban system there are certain requirements that need to be met. Yasuhiro Monden provided a theory in 1983 which consists of a flowchart containing kanban and which goals should be achieved before implementation. The goal that should be achieved before implementing kanban is: standardized operations, setup time reduction, small lot production, reduction of lead time and production smoothing. After these steps kanban can be implemented and profits can be made through inventory cutting and cost reduction by eliminating waste. (Monden 1983)

A generic kanban has the same features as a normal kanban system except that all different variants are considered the same. This means that when a kanban call is initiated it is not necessarily the same parts as the previous ones that are being replenished. In order to specify which part is being replenished a dispatch list specifying the exact item configurations for the next part has to be present. A generic kanban is thus a technique which combines the pull principles of the kanban system with the push principles of a dispatch list. (Jonsson and Mattson 2009)

3.8 Push system

Material planning is of the push type if manufacturing and materials movement takes place without the consuming unit authorizing the activities, i.e. they have been initiated by the supplying unit itself or by a central planning unit in the form of plans or direct orders (Jonsson and Mattson 2009).

In a push system the value adding activity is initiated by a planning unit which ensures that each part of the production process is supplied with sufficient raw material. Using re-order point systems or periodic ordering systems are example of methods concerning this matter. A push system is however not determined by the method that are used but rather which unit is initiating the process. (Jonsson and Mattson 2009)

3.9 Re-order point system

A re-order point system means a material planning method which compares the current stock level with a specific stock level, also known as the reorder point. When the stock level has reached the reorder point a call for replenishment is made. In order to prevent part shortage a safety stock has to be present which covers the production while the replenishment takes place. In order to use a re-order point system information concerning consumption, quantities in stock and the re-order point is required. It is also important to revise the re-order point if the demand varies. A re-order point system is easy to understand and generally well known in industry. It is most commonly used for low value items which often have a frequent and continuous demand as well as for finished goods. It is also beneficial when the usage cannot be planed and a system has to be implemented with bad quality of the input data. (Jonsson and Mattson 2009)

3.10 Software

The DES model has been created and evaluated using Enterprise Dynamics (ED) which is made and distributed by Incontrol Simulation Solutions. ED has an open structure which means that along with features provided by the software itself, it is possible to create features that are not included in the software. An example is the creation of specialized atoms which corresponds to a specific entity that cannot be represented by an atom provided by ED. ED also provides a 3D model view which is generated as the model building takes place. (Incontrol Simulation Software B.V. 2009)

Microsoft Excel has been used in order to create input data to the model and also transfer the data into the model. Excel has also been used for calculation regarding for example validation and analysis. Microsoft Excel is a part of the Microsoft Office suit and is used to create spreadsheets and performing calculations by using predefined formulas or creating your own by using Visual Basic code. (Microsoft Corporation 2010)

3.11 Standardized tasks and continuous improvement

Standardized tasks have its roots back when mass production replaced the craft of production. Much of today's manufacturing company's standardization is based on principles set by Frederick W. Taylor, the "father of scientific management".

Standardized work is much broader than writing out steps the operator needs to follow. Based on three elements the standard work can be set.

- Takt time – Time required to complete the job in order to meet customer demand
- Sequence – The sequence of doing things
- Standardized stock on hand – Stock on hand the individual worker need to have in order to accomplish that standardized work

Processes are impossible to improve before it is standardized. An improvement in a process that is shifting from here to there will only contribute to another variation in the process used occasionally or mostly ignored. A standard needs to be set and thus stabilize the process. Practice must occur securing the standard is followed before any improvement can be made. All suggestions to changes of the process can be compared to the standard. If the suggestion is shown to be better than the standard, then the standard can be changed. This is the basis for continuous improvement. (Liker 2004)

Standardized work is also a key facilitator of building in quality. If a quality defect is discovered within the process the first question asked should be "Was standardized work followed?" If the defect can be traced back to its roots and it is shown those standards were followed, then the standard must be modified. (Liker 2004)

3.12 Waste in manufacturing

When determining what waste is in production, the thing that needs to be investigated is what the customer is willing to pay for. All other activities are classified as waste and should be minimized. According to lean philosophies there are seven (also an eighth type of waste is mentioned, but is excluded in this report) different types of wastes in manufacturing processes. (Liker 2004)

1. **Overproductions** – Producing more products than there are orders on which results in excess of storage, staffing, transportation and inventory**.**
2. **Waiting** – Workers waiting for the next step in the process
3. **Unnecessary transport or conveyance** – Moving material between processes
4. **Over processing or incorrect processing** – Unnecessary processes could for example be greater requirements on quality than needed.
5. **Excess inventory** – Will cause among other things longer lead times, obsolescence, transportation and storage costs. Excessive inventory will also hide problem such as defects, equipment downtime and long setup times.
6. **Unnecessary movement** – Motions operators have to perform during the course of their work.
7. **Defects** – Scrap material but also inspection mean wasteful handling.

The most fundamental waste has been shown to be overproduction, since it causes most of the other wastes. Overproducing necessarily leads to a build-up of inventory somewhere downstream. The material will do no more good than sitting around waiting to be processes in the next operation. Big buffers will also lead to other disadvantages. Having big buffers will reduce the motivation to continuously improve the operations. There will be no need to worry about break downs when a shutdown does not immediately affect final assembly anyway. There will be no need to concern about a few quality errors when there is a huge inventory of spare parts. By the time a defective piece is discovered in a later operation there may be weeks of bad parts within the process and sitting in buffers. (Liker 2004)

3.13 Work in process (WIP)

WIP is a term used in Lean Production in order to describe characteristics of a production system. Measuring WIP aims to visualize how much unfinished material are present in the production process. WIP can be defined as the amount of material of one type that is present in the whole process. This is a way of determine the amount of tied up capital and depict the difference between different alternatives. Even though high WIP states that there are large amount of unfinished goods in the system it does not provide any information regarding the reasons for it. (AccountingCoach, LLC 2010)

4 Results

In this chapter, results are presented concerning the different aspects of this project. First the results concerning how the model is constructed are shown which includes data gathering as well as modeling of the system. In the following sections validation of the model as well as sensitivity analysis are presented which provides information on the validity of the final results. This is followed by the results concerning scenarios for improvement, both for carrier and material not machined in-house. Finally the results concerning critical parameters are presented.

4.1 Data gathering

No previous record over cycle times for different carriers was available even though the cycle time is measured for each run in the machines. Some of the cycle times were noted during the project but the rest had to be estimated. Loading and unloading time for robots were measured in movie clips taken of the robot in process. Each machine was estimated to be stopped for a total time of approximately 30 minutes per shift for tool change. These estimations were made by interviewing operators and production engineers. The total stop time consists of three to four smaller stops. For details concerning input data for machining of carrier see Appendix C.

According to operators the robots were really reliable with almost no break downs at all. Therefore breakdowns for robots were disregarded. Even major break down in machines were not taken into consider due to no available data and according to operators break downs were extremely unusual.

Input data concerning lever and crossbar were received from the production department and through interviews as well as time studies. Times considering cycle time was found to be more or less constant while loading and unloading were more varying. Tool changes are made each shift and estimation concerning these results was made and can be found together with data for cycle times in Appendix C.

The time study that was conducted generated results concerning cycle times and set up for the assembly and pre-assembly. In order to do the time study efficient important stations were determined prior to execution. These important stations were evaluated more carefully than the others. Which stations that are considered more important can be seen in Appendix D. The data concerning the different stations at assembly and pre-assembly can be seen in Appendix C.

On ten orders information on actual packaging instructions were missing. Those ten orders contained 321 products compared to the total of 10745 products. Packaging instructions that couldn't be retrieved were assumed to be packed with nine in each pallet if the order size were nine or greater. Smaller orders than nine were packed according to order size. How the orders were packed in the simulation model can be seen in Appendix C.

4.2 Modeling the production system

The simulation model is designed with basis of the conceptual model which can be seen in Appendix A. In order to gain correct distances for forklifts, conveyors etc. a drawing of the actual factory facilities has been used as a background image. Because of the location of assembly and machining is in to different factory halls the separation can also be seen in the simulation model. The modeling resulted in a very complex simulation model with a high level of detail which sets high demands on computer performance in order to perform a run in reasonable amount of time. See Figure 3 for a view of the simulation model.

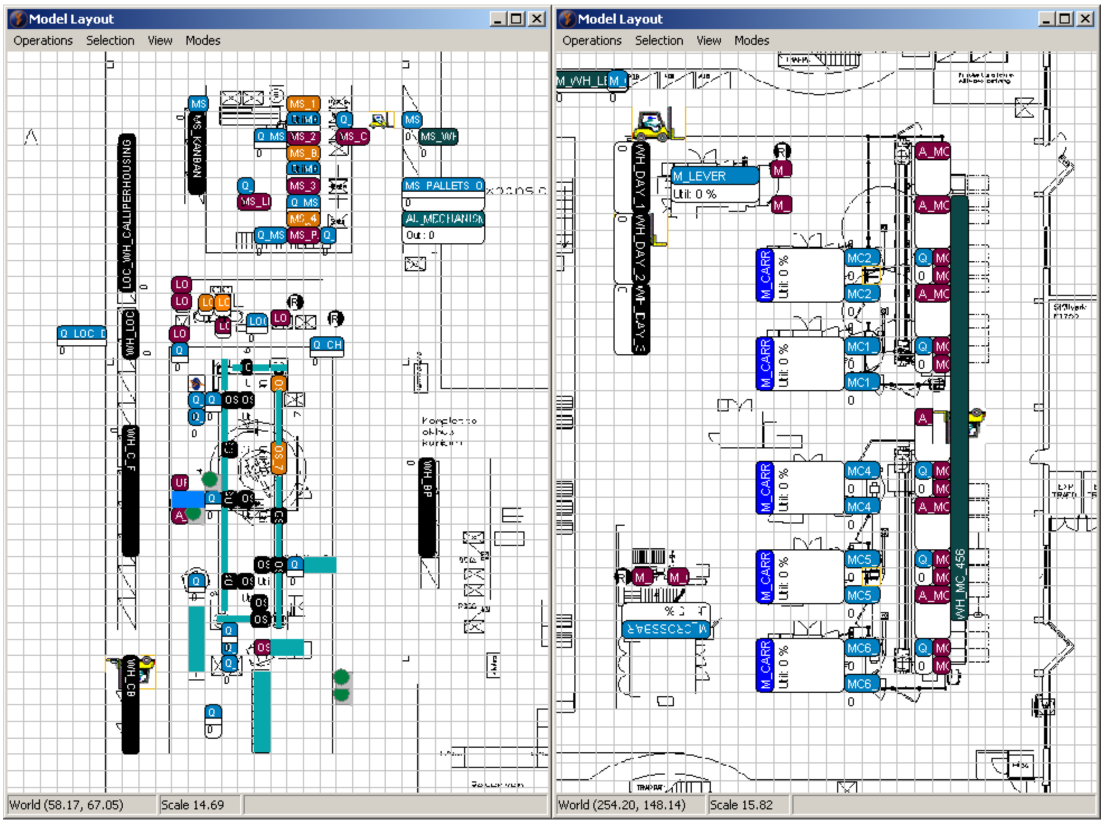

Figure 3 – Screen captures of the simulations model. Left represents assembly and right represents machining.

4.2.1 Input data to the model

Much of the data are fixed data or distributed data gained from data gathering. Other data have been used as input variables in order to gain different results from the model in the different scenarios. Compared to the native stage the order planning has been changed in the different scenarios. Starting machining one week ahead of assembly. Regulations on forklifts have been establishes as allowed time intervals for transportation. Data for dedication have been modified for only allowing machine 4, 5 and 6 for processing carriers.

The main variables that have been varied in the different scenarios are the sizes of the different warehouses dedicated for the different type of carriers and allowed overflow. One of the scenarios has also affected the order planning with a removal of carrier 91617 to kanban.

4.2.2 Output data

The data logged and used to evaluate the different scenarios after performed runs are; WIP, Productivity, maximum used space in each warehouse, failure in fetching material, failure when trying to leave material at assembly and number of setups in machining.

4.2.3 Machining carrier

The production plan for carriers is performed manually based on both forecasts and orders. There is no available record over historical production plans and it is not very straightforward how machines can handle different carriers. Since simulation model is based on the traceability and eight weeks of production that will require more than 10 000 carriers it is not possible to make a manual production plan for these carriers in the model. An algorithm that automated this process was designed according to Figure 4. The algorithm is based on the fact that the machining of carriers is restricted by the number of outputs. In order for a carrier to be processed it first needs to have an available output. Once an output is available it will be necessary to search for a fixture that is dedicated for the special type of carrier. If no matching fixture is available another carrier will be tried out instead. If no carriers can be processed the algorithm will be triggered again once a fixture becomes available.

The conditions on the right side of the grey crosshatched line enables more than three fixtures operate simultaneously. This part is also restricted by how far the algorithm will search for orders in the queue. This because common carriers like 91617 won't get over prioritized causing other carriers to be delayed.

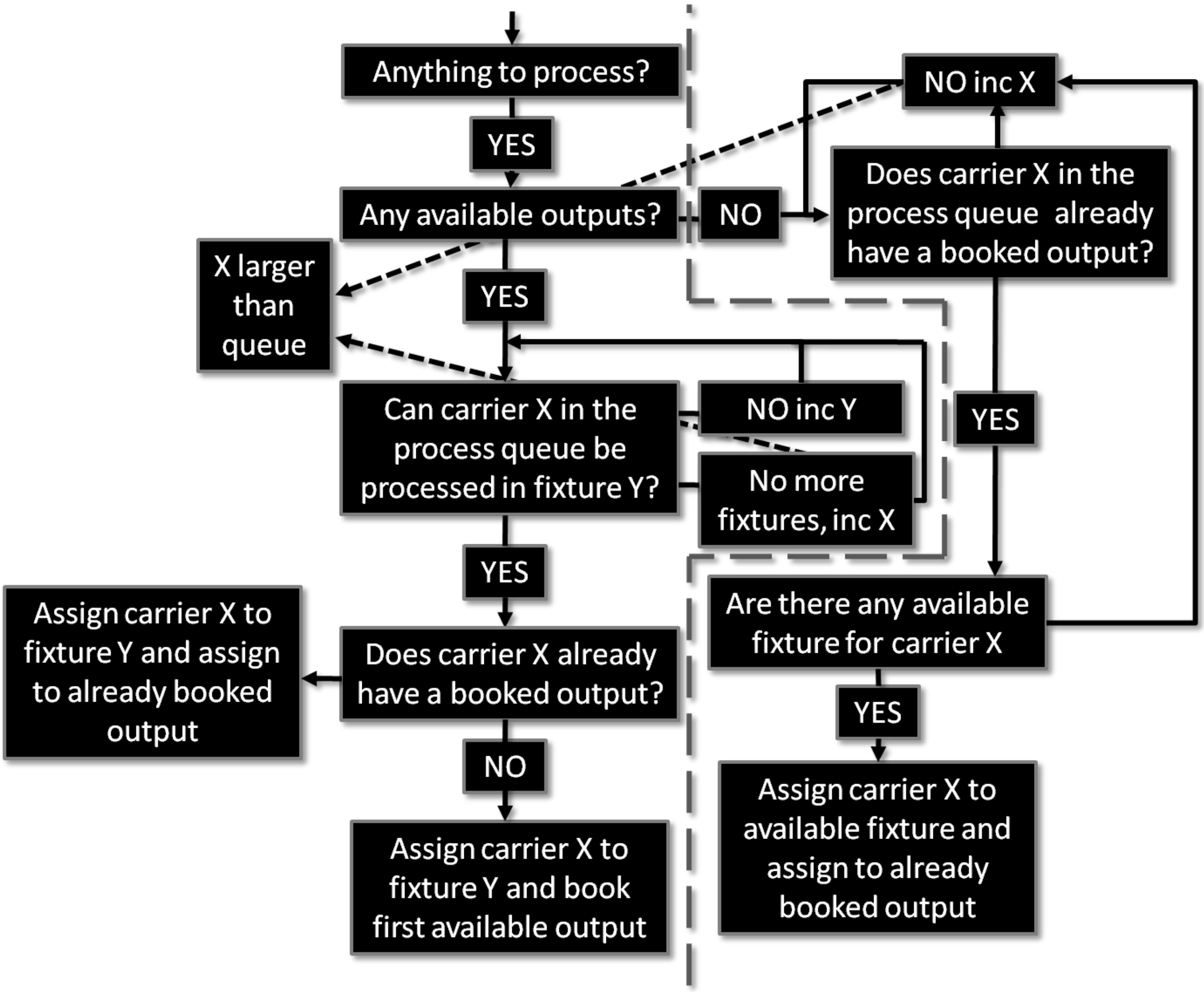

Figure 4 - Algorithm for production planning of carrier

In the reality it is possible to find more optimal situations that will increase efficiency. The simulation model will therefore act as a worst case scenario enabling results from the model to be trustworthy because it will be possible to do at least as good as the model in reality.

4.2.4 Dedications of fixtures

At current state five machines can be used to machine carriers. In a future state it will only be possible to utilize three machines. A rededication needs to be performed and in the simulation model the fixtures have been dedicated according to Table 3.

Table 3 - Dedications of fixtures in machining

Machine 4	Fixture 1	91617
	Fixture 2	91617
Machine 5	Fixture 1	91062, 93026, 92818, 94920, 92828
	Fixture 2	90785, 91617, 90787, 92075, 93530
Machine 6	Fixture 1	92828, 93026, 92818, 91062
	Fixture 2	90638, 90782, 91070, 91071, 91072, 91073, 92392, 91069, 94658

4.3 Validation

The results of validation for pre-assembly, assembly as well as for machining of lever, crossbar and carrier are shown in Table 4, Table 5, Table 6 and Table 7. The tables contain comparisons between model and reality concerning availability, output, efficiency and OEE. In order for validation to be satisfactory the difference between model and reality should be between ±2percent.

Table 4 - Validation of pre-assembly

	Availability		**Output**		**Efficiency**		**OEE**	
Week	Model	Reality	Model	Reality	Model	Reality	Model	Reality
2	1,00	1,00	959	1334	0,44	0,62	0,44	0,62
3	0,99	0,99	1319	1082	0,61	0,51	0,61	0,50
4	0,98	0,98	1408	1262	0,66	0,60	0,65	0,58
5	0,99	0,99	1259	1069	0,59	0,50	0,58	0,49
6	0,98	0,99	1428	1468	0,67	0,69	0,66	0,68
7	0,99	0,94	1775	1611	0,83	0,79	0,82	0,75
8	0,97	1,00	1574	1664	0,75	0,77	0,73	0,77
9	0,98	0,97	1532	1422	0,72	0,68	0,71	0,66
10	0,97	0,97	1080	1465	0,51	0,70	0,50	0,68
Avg.	0,985	0,981	12333	12377	0,645	0,650	0,634	0,637
Dif.	0,40%		-0,35%		-0,79%		-0,35%	

Table 5 - Validation of assembly

	Availability		Output		Efficiency		OEE	
Week	Model	Reality	Model	Reality	Model	Reality	Model	Reality
2	0,95	0,928	842	897	0,51	0,56	0,48	0,52
3	0,96	0,951	761	757	0,45	0,46	0,43	0,43
4	0,95	0,961	706	699	0,42	0,42	0,40	0,40
5	0,95	0,928	717	668	0,44	0,41	0,41	0,38
6	0,87	0,938	1230	1264	0,79	0,77	0,68	0,73
7	0,87	0,944	1271	1189	0,81	0,72	0,71	0,68
8	0,85	0,867	1045	1047	0,68	0,69	0,58	0,60
9	0,93	0,866	810	823	0,49	0,55	0,46	0,47
10	0,98	0,977	549	616	0,32	0,36	0,31	0,35
Avg.	0,924	0,929	7930	7960	0,546	0,549	0,498	0,508
Dif.	-0,53%		-0,37%		-0,48%		-1,92%	

Table 6 - Validation of machining concerning carrier

		Heller4		Heller5		Heller6		Total	
v		Reality	Model	Reality	Model	Reality	Model	Reality	Model
	2	292	280	292	280	394	140	978	700
	3	110	280	140	420	108	56	358	756
	4	352	364	350	448	308	308	1010	1120
	5	378	336	396	532	222	448	996	1316
	6	364	224	412	336	372	224	1148	784
	7	430	336	318	252	330	140	1078	728
	8	478	168	238	224	250	140	966	532
Tot.		2404	1988	2146	2492	1984	1456	6928	6440
Dif. (tot)		-17%		16%		-27%		-7%	
Max/day		124	118	120	128	124	130		
Dif. (max)		-5%		7%		5%			

Table 7 - Validation of machining concerning lever and crossbar

		Lever		Crossbar	
v		Reality	Model	Reality	Model
	1	344	1797		
	2	1592	1198	1878	1498,2
	3	144	1198	996	1200
	4	1808	1797	1590	1199,2
	5	1184	1198	1416	1679
	6	2088	1797	1236	1440
	7	1978	1198	1530	1658,2
	8	2128	1198	1104	1220,6
Tot.		11266	11381	9750	9895,2
Dif.		1,02%		1,49%	

Since the current demand is low in comparison to what the system is designed for, comparison on a daily basis was hard to make since the reality varies very much from day to day. In order to evaluate the system daily production has been monitored and the results for pre-assembly and assembly have then been analyzed by visually plotting the daily production in the model compared to the reality. The graphs for assembly and pre-assembly can be seen in Appendix E.

When running the output for machining of carrier, level and crossbar through operators and engineers positive responses were received concerning the daily output. In order to get information concerning validity of other parameters than output more interviews were conducted. The operators and engineers provided information pointing towards very few disturbances in terms of break downs and other stops.

4.4 Sensitivity analysis

The iterative approach for finding the maximum increase of all variables provided the following results:

1. Increase of 30%: 2/5 runs with faults
2. Increase of 20%: 0/5 runs with faults
3. Increase of 25%: 0/5 runs with faults

The approach for finding the highest increase for the unknown cycle times, which were considered the most significant variable, provided the following results:

1. Increase of 50%: 2/5 runs with faults
2. Increase of 40%: 0/5 runs with faults
3. Increase of 45%: 0/5 runs with faults

The final approach concerning finding the maximum increase of the least significant variables, change of tools frequency, change of tools duration and set up duration, provided the following results:

1. Increase of 60%: 5/5 runs with faults
2. Increase of 50%: 4/5 runs with faults
3. Increase of 40%: 1/5 runs with faults
4. Increase of 30%: 0/5 runs with faults
5. Increase of 35%: 0/5 runs with faults

4.5 Scenarios for experiment

All scenarios are based on production plan of machining is issued one week ahead of assembly and the production is based on actual demand instead of mixture of forecast and demand. In the kanban scenario there is one exception where one type of carrier is produced on kanban calls.

In order to avoid situations where forklift are forced to return material due to lack of available space at assembly two rules are set up for the trucks. Carriers with dedicated pallet slots are emptied from machining at Wednesdays and Fridays after assembly shift ends. Undedicated carriers are assumed to always have space at assembly and can therefore be emptied daily.

The first scenario will only have minor impact on changing the behavior in the production. All scenarios except the reducing dedication scenario will have a significant impact on the machining processes. Instead of always process full pallets with 28 carriers the suggestion will be to process just as many as there are orders on. The different scenarios with results are described below. The results from the different scenarios can be seen in Table 8 and Figure 7.

4.5.1 Scenario reducing dedication

In the current stage many carrier that are used seldom share space in a certain area. Carriers that had not been used at all or seldom the latest period were moved into this area and other warehouses were reconfigured to be more proportioned to the demand for this period. In order to investigate if further space could be freed a hybrid area for dedicated carriers were added next to the fixed slots. This hybrid area acts as an overflow letting the carriers with fixed slots extend its capacity during shorter period when demand fluctuates.

The reducing dedication scenario consists of two different configurations of the pallet dedications. In variant A the four most frequent used carriers are dedicated to a certain number of pallet slots. The sizes of the dedications are based on the common week need of each carrier. The distribution of the need of each carrier can be seen in Appendix B. These carriers also have the possibility to utilize a hybrid overflow shared by all four carriers. All other carriers share space without any dedication. The scenario covers 15 different carriers. Adding one more carrier will also require one more pallet slot in the shared area due to reason that a minimum of 28 carriers needs to processed regardless order size. The feasible configuration with least pallet slots for variant A can be seen in Table 8. In variant B no carriers more than 91617 is dedicated. This will enable even more space to be freed. The overflow can be utilized by all types of carrier including 91617.

4.5.2 Scenario varying batch

The varying batch scenario matches the number of machined carriers with the order sizes. A production of carrier is allowed to be combined for different orders if the different order have the same carrier and will be assembly after each other. All pallets will always be emptied at assembly and never put back to pallet storage. Adding one more type of carrier will therefore not require one more pallet slot. As in the reducing dedication scenario there are two variants of this scenario. They are both the same as in previous scenario except matching carrier with order sizes.

4.5.3 Scenario daily production

Producing carriers by matching the exact order sizes enables a new way of storing the carriers. The solution was based on a different way of categorizing carrier. Instead of categorizing carrier by type they were categorized by the day they were supposed to be assembled on which enable the warehouses to contain any type of carrier. One week’s production have been divided into five days with 270 carriers per day, rounded off to nearest full pallet. The carriers are moved from machining to assembly with one day’s need of carriers at a time. It is possible to be working on one to three day needs at a time in order to keep a high utilization on the machines. The first day in turn is always prioritized. Once a day’s need is machined it can be moved to assembly if the corresponding day at assembly is empty. See Figure 5 and Figure 6 for the configuration of the pallet slots. The empty area is freed area compared with the current situation.

In the simulation model there is a delay of two hours starting counting when a day has been machined or emptied at assembly depending on what happens last. This means that in reality the carriers need to be moved within two hours counting from whenever it is possible to complete a transport.

According to the eight weeks of production, splitting up the week's production into day production has never caused a need greater than 15 pallets per day. To be able to have five days of need of carriers in production it will be necessary to have room for three days at machining and three days at assembly.

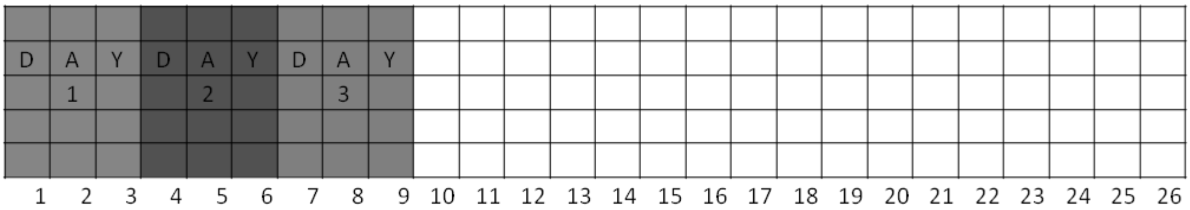

Figure 5 - Configuration for day by day deliveries at assembly, Scenario daily production

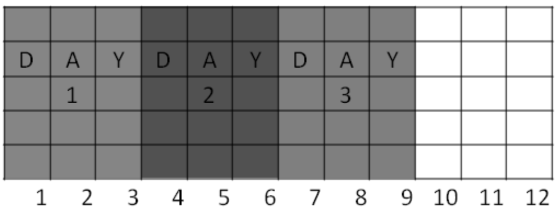

Figure 6 - Configuration for day by day deliveries at machining, Scenario daily production

4.5.4 Scenario kanban

According to the requirements stated by Monden (Monden 1983) the only carrier that is suitable to be regulated by kanban is 91617. All other carrier are fluctuating heavily in demand and a kanban solution for them would require a lot of tied up capital and allocated space by machined carriers. In the kanban scenario, 91617 is produced on kanban calls and all other carriers are handled as in scenario varying batch, with two variants of the scenario. A kanban card consists of three pallets and simulation results indicate a need of ten kanban cards. There is two hours delay for starting the production of 91617 starting counting from when the kanban card is issued from the assembly. In variant B it is not possible to have an overflow between 91617 and other carriers.

Table 8 –Results for scenario reducing dedication, varying batch, daily production and kanban (seen as I, II, III, IV with respective variants A and B). The numbers under assembly and machining are the amount of required pallets slots.

		Assembly								Machining				Productivity in machines				
Scenario		90782	91072	91062	91617	Overflow	Shared	Backup	Total assembly	Dedicated	Un-dedicated	Total	Setups / week	4	5	6	Mean	WIP
Current									**130**		60	**190**						
I	A	2	2	4	26	16	40	5	**95**	30	12	**137**	6,75	91,5%	98,0%	89,6%	93,0%	1543
	B				25	5	40	5	**75**	21	14	**110**						
II	A	2	2	4	25	17	33	5	**88**	30	12	**130**	7,38	94,0%	96,4%	89,4%	93,3%	1405
	B				25	5	35	5	**70**	21	14	**105**						
III							45		**45**		45	**90**	7,5	87,4%	93,5%	85,2%	88,7%	1328
IV	A	2	2	4	30	15	35	5	**93**	12	12	**117**	8,13	76,9%	94,8%	87,6%	86,4%	1402
	B				30		45	5	**80**	3	12	**95**						

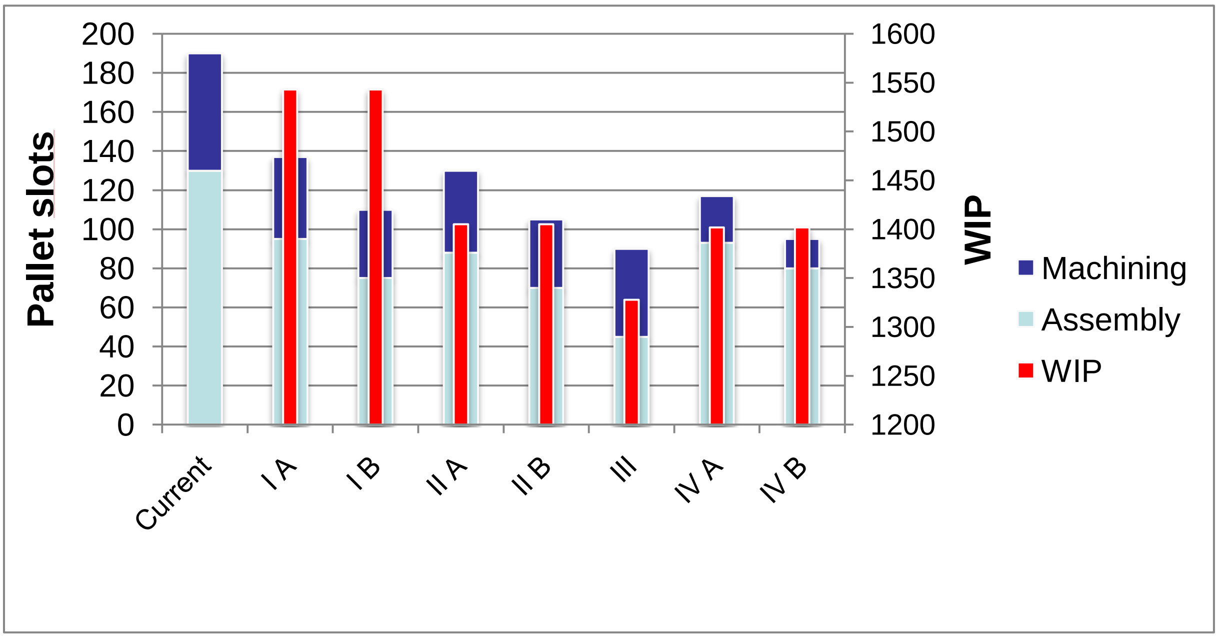

Figure 7 – The number of required pallets slots and the wip presented in a diagram for scenario reducing dedication, varying batch, daily production and kanban (seen as I, II, III, IV with respective variants A and B).

In Table 8 all the results from the different scenarios have been compiled together for comparison. In Figure 7 the WIP and the required amount of space is visualized. Scenario daily production has resulted in the smallest amount of required pallets slot in total and at assembly and also the lowest WIP. When comparing required pallets slots at machining scenario kanban is the suggestion with least amount of required space. Information regarding productivity in machines and WIP are also presented.

4.6 Materials not machined in-house

There are four different sizes of pallets present for the parts not machined in-house. Since the demand is based on worst case scenario i.e. the same demand for all parts, only these four sizes has been put through Formula 2 for the reconfiguration scenario. The results are shown in Table 9.

Table 9 - Results from kanban formula

Pallet size	24	32	42	56
D (parts/2h)	109,0909	109,0909	109,0909	109,0909
L (2h)	1	1	1	1
alp	0,2	0,2	0,2	0,2
a	24	32	42	56
n	5,454545	4,090909	3,116883	2,337662

These results show how a kanban system should be configured when each pallet has one kanban card. This scenario is called variant A in order to distinguish between the scenario with one kanban card per pallet and the following scenario.

The results from the modified MRP are used in order to see how a system with less kanban cards function. This configuration is called variant B ant the results are shown in Table 10, Table 11, Table 12 and Table 13 concerning the following systems:

- Pallets containing 24 parts, 6 pallets and 3 kanban cards
- Pallets containing 32 parts, 6 pallets and 3 kanban cards
- Pallets containing 42 parts, 4 pallets and 2 kanban cards
- Pallets containing 56 parts, 4 pallets and 2 kanban cards

The MRP has been constructed with a non-linear time axis and with important events generating the time.

Table 10 - MRP with pallets containing 24 parts, 6 pallets and 3 kanban cards

Time (min)	0	57,6	115,2	172,8	177,6	235,2	292,8
Stock	144	96	48	0	48	48	48
Production	48	48	48	0	48	48	48
Arrival of order	0	0	0	0	48	48	48
Order	0	48	48	48	0	48	48

Table 11 - MRP with pallets containing 32 parts, 6 pallets and 3 kanban cards

Time (min)	0	76,8	153,6	196,8	230,4	273,6	307,2
Stock	192	128	64		64		64
Production	64	64	64		64		64
Arrival of order	0	0	0	64	0	64	
Order	0	64	64	0	64	0	0

Table 12 - MRP with pallets containing 42 parts, 4 pallets and 2 kanban cards

Time (min)	0	115,2	230,4	235,2
Stock	168	96	0	96
Production	96	96	0	96
Arrival of order	0	0	0	96
Order	0	96	96	0

Table 13 - MRP with pallets containing 56 parts, 4 pallets and 2 kanban cards

Time (min)	0	134,4	254,4	268,8
Stock	224	112		112
Production	112	112		112
Arrival of order	0	0	112	0
Order	0	112	0	112

A shortage of parts for five minutes can be seen in the first and last MRP. There are, however, factors that removes this shortage which will be shown in the analysis chapter.

For scenario daily replenishment, Formula 1 provides the following results:

- Component 1: 17 slots
- Component 2: 20 slots
- Component 3: 16 slots

The single runs that were made in order to evaluate the scenario looked as follows:

1. Component 1 16, Component 2 20, Component 3 16.
   The scenario generated large amount of faults concerning component 2 but also faults concerning component 1 and component 3.
2. Component 1 20, Component 2 25, Component 3 20.
   The run generated no faults concerning all three parts.
3. Component 1 18, Component 2 23, Component 3 18.
   The run generated faults concerning component 2 and component 3.
4. Component 1 17, Component 2 24, Component 3 19.
   The run generated no faults concerning all three parts.

The single runs suggest a configuration where component 1 has 17 slots, component 2 has 24 slots and component 3 has 19 slots. The multiple runs for this configuration generated faults concerning component 1 while no other faults. An increase of slots for component 1 to 18 tested in multiple runs generated no faults. The configuration can be seen in Table 14.

Table 14 - Visualization of scenario reconfiguration, variant A and B (seen as IA and IB) and scenario daily replenishment (seen as II) as well as the current situation concerning pallet slots

	Component 1				**Component 2**								**Component 3**						
Scenario	89950	89738	91067	Shared	92663	91969	91974	92001	92002	92741	93449	Shared	94783	94784	94785	94786	Shared	Total	Kanban cards
Current				*26*								*30*					*30*	***86***	
I A	6	5	5	0	4	4	4	4	4	4	4	0	3	3	6	6	0	**62**	**62**
I B	6	6	6	0	4	4	4	4	4	4	4	0	4	4	6	6	0	**66**	**33**
II	1	1	1	15	1	1	1	1	1	1	1	17	1	1	1	1	15	**61**	**0**

4.7 Critical parameters

Six parameters have been found to have critical effect on space allocation in the production system. These six parameters are:

1. **Production planning** – The configuration of the production planning concerning mainly the release time.
2. **Amount of variants** – How many variants that are present for each specific part.
3. **Overproduction of carriers** – Overproduction of carriers in order to achieve 28 parts in each pallet.
4. **Dedication of pallet slots** – Dedication pallet slots for a special variant of a part.
5. **Truck frequency** – How often the trucks are allowed to transport parts between machining, central storage and the assembly.
6. **Resilience of machining and pre-assembly** – How resilient the system is concerning up-time and production rate.

5 Analysis

In this chapter an analysis concerning the results for the different scenarios both for carriers and materials not machined in-house is made. In the final section the critical parameters that were found are analyzed.

5.1 Analysis of the different scenarios for carriers

The different scenarios are based on production planning for machining is issued one week ahead of assembly and the production is based on actual demand instead of forecast. This means that assembly plan needs to be prepared five days ahead. If customer have high demand on receiving their products in shorter time than five days none of the scenarios will be possible to implement in reality. In that case the scenarios must be complemented with some kind of extra stock for carriers that will require shorter lead time than five days. If this is only valid for carrier 91617, the kanban scenario will still be able to handle this problem. The scenarios are also intended to be continuously improved in future stages enabling even shorter lead times. Then any extra stock won't be necessary.

The machines for processing carriers are design to take two carriers at a time. Matching production plan in machining with incoming order that is not an even number will cause some problem that needs to be considered. One solution could be to on every second odd order produce one more carrier and one less the other time. The extra carrier then needs to be stored at machining but this will require a maximum of one carrier per variants that could be stored in the same pallet.

5.1.1 Scenario reducing dedication

The scenario has its advantage with an easy way of implementation but will also result in a low number of freed pallet slots. The machining can go on basically in the same way as in the current stage. The scenario is quite sensitive for the distribution of the demand for the different carriers if variant A I chosen. Placing more carriers in the shared area as in variant B will decrease the sensitivity for fluctuation in demand for the different carriers. But adding many carriers to a shared area will cause some problems. The operator will need more time to find the desired pallet. The operator does not just need to find a pallet with the right content but must also assure that the pallet that has been in storage for longest time is first to be taken.

There is also a consequence with continuing producing a minimum of 28 carriers regardless if the need is only for one or a full pallet. This will require the rest of the carriers to be put in storage at assembly until a new order on the specific carrier appears, which can take very long time and in a worst case the carriers can be stored for years and occupy one pallet slot for the entire time. This will also mean that introducing one new type of carrier will require one more slot in storage.

5.1.2 Scenario varying batch

The greatest advantage with scenario varying batch is that no carriers will be left in storage for more than one week. Once an order is assembled the carrier's pallet will be empty or ready for next order if the next order requires the same carrier. As in scenario reducing dedication the same disadvantage will imply for variant A compared to B. But there will be no problems by adding an additional type of carrier.

5.1.3 Scenario daily production

The greatest advantage with this scenario is that it is not affected by the distribution of the different variants of carriers. Also the advantages in scenario varying batch will be valid for this scenario. The scenario is the best solution when considering minimizing the need for storage at assembly. 15 pallet slots will be required to cover one days need but it will be possible to use each day's pallet slots as backup if 15 wouldn't be enough for one day. It will be easier for the operator to find the pallet when there will be no more than three columns to search in. This can also be done even easier if the pallets are labeled in correct order. Then truck driver can stack pallets in correct order when moving pallets from machining.

The scenario has good opportunities to be improved in future stages. By improving the machining it will be possible to decrease the number of days in process. The next step would be to remove day three in both machining and assembly which will result in a reduction of lead time with two days. A future improved scenario would be only one day at machining and one day at assembly and one day in lead time. It will be easy to follow the flow in production and to see if machining is on schedule by looking at the different storage shelves and see if they are filled or not. The communication to responsible truck drivers could be simple. Once a day has been emptied at assembly and one day at machining is ready, the transportation of one whole day's demand can be fulfilled at one occasion.

Some disadvantages must be considered when implementing the scenario. There are currently nine shift per week working in machining and five shifts at assembly per week. One day's production is not equivalent or even divided between machining and assembly. With nine shifts available, the machining needs to produce 0,556 days need of carriers per shift which could cause some difficulties in production planning. The need of one day ought to be fitted into 15 pallets. Small orders will require one whole pallet if they can´t be combined with other orders with the same carrier. The production plan used in the simulation model has never required more than 15 pallets per day.

If the scenario would be continued improved with shorter lead time and an increase in the resolution of the categories (from days to hours, to minute and so on) eventually the final solution would be an ideal one piece flow. But implementing a one piece flow wouldn't be possible without radical changes in the machining processes which stands aside this projects focus. This scenario would instead be an adequate foundation with grate possibilities for continuous improvements.

5.1.4 Scenario kanban

In scenario kanban carrier 91617 is withdrawn from the production planning of carriers, which can make the planning somehow easier. When using both machine four and five for processing 91617 it won't be possible to know if 91617 will interrupt machine five or not making it harder to plan carriers that will be processed in machine five. Simulations have shown that machining in both machines four and five will be needed in order to process a kanban fast enough. A disadvantage is that a set up is often required in machine five when 91617 is to be processed, making the total number of required set ups for the simulation period highest for the different scenarios.

The greatest advantage is the small amount of space needed at machining. When a kanban of 91617 has been processed it can directly be moved to assembly. Assembly storage has also been design ensuring all other carriers can be transported once a day.

5.1.5 Analysis of scenario performances

The productivity for the first scenario was 93 % indicating that in some situations it is possible to produce even more carriers. Looking at the individual machines, carriers that is of a kind that can be processed in machine 6 is the kind of carrier that can be added. The same reasoning is also valid for scenario varying batch. The scenario has an increase in productivity which can be explained by the increase in number of setups. As expected the WIP decreases from scenario reducing dedication to scenario varying batch. In the third scenario (daily production) the productivity decreased distinctly as did the WIP. In the scenario the machining is restricted by the empty warehouses for each day which prevents the machining process from being more ahead of assembly than five days and therefore no more than one weeks need of carriers are in the process.

In the fourth scenario the productivity is very low. The measuring of the productivity starts when all kanban cards are full making the production delayed for each needed carrier produced by kanban. The measurement ends when there are still some kanban cards at machining causes the total number of carriers to be a little bit lower than in the other scenarios. Also the WIP gets quite high compared to scenario varying batch when all kanban carriers are always in production.

5.2 Analysis of the different scenarios not machined in house

The first scenario concerns improvement of the existing system with improved configuration of the kanban system. The kanban formula that was used provides information on how the system should be configured when one kanban card is used to each pallet. This means that when a pallet is empty the kanban card will trigger replenishment from central storage. When one kanban card is used on each pallet, many calls for replenishment are generated, which leads to a high amount of transportation during the day. An effect of this is that the assembly area will be crowded on certain occasions. When considering the rate of production it is easy to understand that during the 120 minutes lead time several other replenishment calls will be initiated. It is reasonable to assume that all these calls are being handled simultaneously and thus decreasing the amount of transportations between central storage and assembly.

Another solution to the problem is configuring the system with some kanban cards containing multiple pallets. This scenario has been tested with the modified MRP and showed, in most cases, no complications. There are four different sizes of pallets and each was tested with MRP. Complications were found for pallets of size 24 and 56. In those cases there was a shortage of approximately five minutes. There are effects that decreases or even removes this complication:

1. As previously stated the lead time of 120 minutes is a worst case and in many cases replenishment are made earlier.
2. A lower production rate than one part per 1, 2 minutes could remove the shortage. The lower production rate could be generated by an unplanned stop or some complication on the assembly line.
3. A change of production concerning which part is being produced will completely remove the shortage.

These assumptions gives that it is possible to configure some parts of the system as one kanban card for two pallets.

Positive effects of the scenario are:

- The organization of the pallets is simple which makes it easy for operators to locate the desired pallet both concerning which part is needed.
- Ensuring FIFO is simple since low amounts of pallets are present for each part.

Negative effects of the scenario are:

- At certain situations there is a risk for shortage of parts.
- The amount of transportations during the production time is high even though some of the calls for replenishment can be handled simultaneously.
- Large amount of material in storage for longer time than desired.

Scenario daily replenishment concerns redesigning the existing system to ensure that only the daily demand is stored at the assembly line. In order to do that, the demanded parts have to be ordered from central storage after each day of production. Since the demand is not always equal to a multiple of the amount in a pallet, slots have to be allocated for pallets which are not empty after one day’s production.

The formula that was used to decide the configuration of the system is not approved by any theory but rather constructed for this specific analysis. This raises questions about the validity of the results which is why simulation was used in order to ensure the validity.

The results acquired from the formula did not generate successful runs in the simulation. This is probably due to spikes in production on certain days. Spikes in production occur when the assembly has fallen behind schedule and are working hard to catch up. Since this is a situation that can occur in reality it is necessary to account for it, thus increasing the allocated slots accordingly.

Positive effects of the scenario are:

- The amount of transportation during the production time is nonexistent since all transportation takes place after the production ends.
- Parts that are stored at the assembly are utilized the same day. An exception is the leftover parts in pallet. These parts will be stored until the next production of said part.

Negative effects of the scenario are:

- Since there are no dedicated spaces, apart from the leftover parts, the organization is less strict.

A way to further decrease the space required it is possible to use a shared pallet slots for component 1 and component 3. This comes since component 3 are not assembled on all products and only assembled on roughly 50% of the final products. It was also found that component 3 are only assembled on final parts which contain component 1 stored in pallets containing 32 parts. Since the amount of space is determined on a worst case scenario with 24 parts in each pallet not all slots dedicated to component 1 are utilized. These two insights shows that shared pallet slots are a possible solution for decreasing the space further.

5.3 Critical parameters

Production planning has a large effect on the amount of space allocated in the production system. This is since the release time of production orders are directly connected to the amount of WIP. If the release time is two weeks prior to assembly it results in two weeks demand of parts are present in the system at all time. If the release time is lowered the amount of WIP will be decreased as well. Changing the production planning has generated good results for the model which further states it as a critical parameter.

A large amount of variants has several negative effects. One of them concerns the utilization of the machining of carriers. In the model all variants of carrier have been dedicated to one or two fixtures. This means that in some cases the amount of variants leads to uneven utilization between the different machines. If dedication of carriers were to be removed the amount of variants would lead to frequent setups. The amount of variants is a reason for keeping the production planning at a long release time, since a more even flow though the machines can be achieved.

Overproduction is especially critical for carriers due to the large amount of variation but also a factor when considering lever, crossbar as well as parts not machined in-house. Overproduction or storage of too many parts leads to high amount of pallets at assembly which are not desired. An example is an order for assembly of 20 specific products. This means that 20 parts of each part are going to be produced or transported into the assembly line. Since there are no pallets that contains exactly 20 parts each pallet will contain parts after the production is done. Those parts will be lying at the assembly line until the next round of production.

Dedication of pallet slots means that each part has a dedicated slot. This is a good way of organizing a storage area if a constant demand is present. If there are fluctuations in demand concerning each individual part the amount of dedicated spaces has to be configured according to the highest demand which results in excessive storage.

Truck frequency is a factor which has minor effects on the space requirements. During the runs of the model is was noticed that if constant transportation was allowed very low amount of space was required while low frequency resulted in more space requirements. From this it is possible to draw the conclusion that high truck frequency is desirable, but there are drawbacks concerning crowdedness.

Finally the resilience concerning the production system is considered a critical factor. This is due to uncertainties concerning the output of, for example, machining. If the supplying part, in this care machining, are not resilient enough more space has to be allocated to account for variation in output.

6 Discussion

The purpose of this project was to provide several improvement scenarios to the company, which could be implemented in order to reduce the amount of space needed in storage. Together with the generated scenarios critical parameters concerning the amount of space needed have been identified throughout this project.

Some of the critical parameters have effects on other parameters as well. This is especially true concerning the amount of variants which also affects the amount of overproduction and the dedication of specific parts. These results show that for future products it is necessary to take these factors into consideration. It is possible to minimize the negative effects concerning the amount of variants if the machining is versatile enough to keep a high utilization as well as machining different amount of parts. If a large amount of variants are present it is also beneficial to keep random storage instead of dedicated storage which is also stated by Tompkins (Tompkins, et al. 1996). When it comes to production planning it is desirable to keep the lead times as low as possible in order to decrease the amount of parts in storage. When considering truck frequency it is desirable to keep a high frequency of transportation. One way of accomplishing this is to keep the different production areas concerning a product close enabling transportation to occur more or less continuously, possibly without using forklifts.

Many of the scenarios concerning carrier are based on allowing production of less than 28 parts at the time. Positive effects of this have been presented in the report concerning for example reducing the amount of pallets with left over material i.e. eliminating waste in the form of overproduction which was stated by Liker (Liker 2004). There is however negative effects connected to performing this change especially for a short time frame. These negative effects are for example cost of performing the change (re-programming of production cell and determining new work standards) as well as a risk of lower productivity due to a new way of working. These negative effects, as well as others, have to be evaluated more thoroughly even though the positive effects in the long run are significant.

All scenarios concerning carrier that have been suggested in this project have used less dedication concerning pallets slots and to a larger extent randomized storage. This has lead to reduced amount of pallet slots which is consistent with theory stated by Tompkins (Tompkins, et al. 1996)**.** The scenario that has been shown to be the most beneficial is the daily production scenario, which needs fever pallet slots compared to the other suggestions. This is caused by the lead time which is more strictly confined to five days for scenario daily production. When only considering the warehouse at assembly the lead time for scenario daily production is three days maximum while the other scenarios can keep up to five days. These findings are consistent with the theory presented by Liker concerning waste (Liker 2004).

Scenario daily production is the only suggestion that can cope with the different types of carriers regardless of future demand. All other scenarios will need to be revised after a certain period to match the dedication of pallets slots with the actual demand. The A scenarios are even more sensitive and would require more frequent revisions. The daily production scenario suggestion is also the one that put the highest demand on performing changes. The production planning needs to be performed in a new way and machining must be prepared for more frequent setups. But this is probably actions that the company needs to take in order to cope with all variants. The alternative is to keep the old way of storing product which will require much space, long lead times and high level of tied up capital in semi-finished products.

This project does not consider quality defects. Scenario reducing dedication, varying batch and kanban are based on actual orders and no forecasting and if a quality defect would be discovered at the assembly line no spare parts would be available. There is also a problem in machining of carrier where the machines need to take two carriers at a time. If an odd number of carriers would be required to fill one order it would be necessary to produce one extra carrier. A solution could be to combine the quality problem with the machining problem and store one or more spare parts that also could act as storage to fill up the odd order numbers. The problem is where to put this storage. The extra odd carrier would be needed at machining whereas the spare parts should rather be placed at the assembly line. Anyway it is a problem that could fairly easily be solved.

Generating the scenarios for parts not machined in-house was performed at a later stage of the project when deciding to perform a deeper analysis of the warehouse in the assembly area. This is why there are only two different scenarios concerning these parts. The scenarios are however considered sufficient since the first scenario concerns minor modifications while the second scenario concerns a new way of thinking and working. This fact is important to take into account when deciding which scenario to implement. Apart from amount of change, factors such as space, lead time for specific parts, truck frequency and organization were considered when the analysis was made. In terms of space and lead time for specific parts the daily replenishment scenario were determined to be the most beneficial while scenario reconfiguration were considered better for the other factors. This project believes that the daily replenishment scenario will generate the most benefits for the Company especially if a “loose” organization is implemented by the operators.

Implementing a “loose” organization concerning pallet slots is also beneficial when considering scenarios for carrier. Implementing a “loose” organization could mean storing parts sequenced by number instead of totally random. This approach could improve the working conditions for operators when finding which material to use next.

WIP and productivity were the two performance measurements considered in the simulation model. There were also discussions concerning measuring internal lead times. The lead time is easy to measure in the model but the output will be much harder to analyze. Production does not take place 24 hours a day meaning that the time when there is no production needs to be withdrawn from the lead time. Working two shifts at assembly and one at machining also causes the internal lead time to be unevenly distributed during the day. An increase of WIP will however require longer lead times, in order to get through the production. This resulted in the conclusions that no more benefits would be gained by measuring the lead time, the comparison between the scenarios could be done anyway. There were also discussions regarding measuring a service level that would show how often trucks transports were performed successfully and materials were available at the assembly. But all scenarios have been elaborated with a service level of 100 % which causes the service level to be less useful when comparing the different scenarios.

Simulation has been a great tool when analyzing and validating the different scenarios that have been generated in the project, although the simulation tool has not automatically generated the scenarios. Other methods have been used for this purpose which is not connected to simulation methodology. The benefits of simulation in this project are instead the validation of the scenarios. This methodology has proven that the scenarios actually will be feasible, which could be questioned otherwise.

There were some situations that couldn't be modeled. The operator responsible for fetching material to the different stations at the assembly was also responsible for packing finished products. The operator would have plenty of time doing that as long as finished products were packed more than four at a time. Packing four products take as much time as pack 16 but will occur four times as often making the operator heavily loaded and could cause a stop at the assembly line. In reality though, when this occur the operator is helped by other colleagues in order to avoid overloading and restrictions of the production flow. At the packaging station four or more products were always packed together compared to reality where packing of four or less products were done on one or two half pallets which in the simulation model gave the same results as pack four on one whole pallet.

Much time in the project were put into making the assembly line very detailed. The setups on the stations consisted of switching materials and one operator driving a forklift were responsible to supply all stations with material. The level of the detail were made very high for this forklift due to the fact that it would constrain the production line if the operator didn´t have time enough to supply all the stations. Smaller order sizes would increase the frequency of how often a setup would be required. The high detail would enable analysis of how small order sizes could be processed in order to still cope with all the setups while keeping only one truck driver. This was a factor stated by the company, but unfortunately were any further analysis never made.

The simulation model runs the scenarios with no inventory at initial stage. This must be taken into consider when implementing one scenario in reality. Scenario reducing dedication, varying batch and kanban will require carriers stored at assembly to be removed or be combined to incoming orders during an implementation phase. Old carriers that have not been used during this period must be removed from assembly storage. In the scenarios where carrier are produced according to actual assembly order there will be no room for other carriers at pallet slots reserved for the intended scenario.

The algorithm that solves the planning of the machining of carrier has some drawbacks compared to the reality. The algorithm sends carriers to certain fixtures in the different machines. The fixtures has a predefined dedication, however switching raw material will cause a set up. In reality there is a possibility to change the order in the production schedule enabling a reduction of the number of required setups. The algorithm does not take this into consideration when choosing which carrier to process. Therefore results from the model will indicate more setups than might be required in reality. The simulation model will therefore act as a worst case scenario enabling results from the model to be trustworthy because it will be possible to do at least as good as the model in reality.

The algorithm could be used in reality as an aid when setting up the production plan. The simulation model could also be useful when analyzing different kinds of dedications in the machines. In the model it is possible to analyze how different dedications will affect the distribution of utilization for the machines. The chosen eight weeks of production has shown that the distribution has been surprisingly even. If the distribution should have shown to be uneven a much more complex algorithm would have been needed to be elaborated which also included the possibilities to change the entire fixtures. This is probably something that needs to be considered in future scenarios when new carriers will be available and the distribution will fluctuate even more.

The simulation model is also restricted by the three available outputs from the robot cell. In reality there is a fourth option available enabling the robot to put carriers on a conveyor used for manual inspection. This can result in situations where in the model one machine cannot be used when blocked with no available outputs, whereas in reality a machine could be allowed to leave material on the conveyor. The reason for this option was not implemented in the model was that using the conveyor would require some manual labor that could require more workforce than what would be available in reality at the high production volume.

There are many uncertainties concerning the gathered data in machining, one of them being that no major break downs have been implemented in the model. It is most likely that a brake down in one of the machines will cause effects of the whole production flow. The suggestion in the report has a lead time from machining to assembly of five days. In theory it would take five days before a brake down in machining will cause effects at assembly. Overtime during a weekend in machining could be enough to catch up the loss caused by a break down. Reducing lead time even more would cause the system to be more sensitive for break downs.

The model could have provided more accurate results if all cycle times would have been available for all the carriers. Gathering the cycle time of the carrier is very easy but can only be done when the carrier is in process which for rare carriers occurs very seldom. Operators working at the machining could easily note the time in order to ease the work with future improvements.

Data for trucks are easy to measure but will not be very valid. The trucks speed is very dependent on the operator driving. In the model the trucks have not been analyzed in detail and the input data to the trucks are for that reason not very critical.

Lever and crossbar have a great capacity compared to other parts of the production system meaning that the input data does not need to be very accurate. In reality it will always be possible to catch up the production even if setups or break downs are more usual and take longer time than stated in the model.

The current situation was not ideal for performing measurements at the assembly stations. The particular day the time study was carried out the assembly line was affected by sick leave forcing operators to work on multiple stations simultaneously with a lower takt as compensation. The low takt affected other stations when there was no need to be working at full pace. The current situation has set the actual production pace at assembly line to approximately 700 products a week. If the operators were supposed to produce 1350 products a week it is possible that they would have worked harder or in another manner. There is also a dissimilarity when measuring different operators. The operator’s performance varies and also the way they work. Some operators may work hard and build up a buffer while other work at a more leveled pace.

Different station have different cycle times depending of the type of product. The longest and the shortest cycle time were measured on the stations but there are also stations where there is cycle time in between. The focus of the project has not been to analyze the processes meaning that really accurate data for the different stations are not vital as long as the output from the assembly line is validated. But this should be considered if the measured times were to be used in other forms of analysis as for example process improvements analysis.

The validation of the simulation model was made based upon OEE measurements. An advantage with the approach is that OEE contains information about many different measurements for example availability and output. An important factor when choosing OEE was the amount of available data for pre-assembly and assembly. Unfortunately OEE data concerning machining were nonexistent which led to output being the only comparable measurement. It should be noted that quality is a factor when calculating OEE and serves as delimitation for this project. The effects of not measuring quality were neglected due to scrap rate being low and since several other factors were measured as well.

For pre-assembly and assembly the results were satisfactory, meaning that they were confined in an interval of ±2%. When considering the results it is important to acknowledge that the input data that are fed into the model is based on the data which are used to confirm the validation. This provides that overproduction on a weekly basis is unlikely which raises questions on how the validity would change if a daily perspective were used instead.

Validating the model concerning machining turned out to be more challenging due to the amount of available data as well as the production planning in reality compared to the model. Since there only were available data concerning the output from machining the validation was based on that data. For lever and crossbar the results were confined in an interval of ±2% which is satisfactory. Interviews with operators and engineers showed that the daily production were reasonable.

For carriers there were larger differences between the model and the reality when monitoring the output. There are some reasonable suggestions as to why these differences occur:

1. The production planning in the model differs slightly from the real production planning. The difference is that in reality a some forecasting is included in the production planning whilst in the model no forecasting is made, only products that has been assembled are included in the model’s production plan.
2. Some carriers are machined and then shipped without assembly. These carriers are not included in the model.
3. Differences between the Heller machines are likely to be caused by the algorithm constructed to handle where different carriers are machined.

The delimitation concerning larger changes of fixtures has no effect concerning the validation. This is since these changes are not performed in the current situation. If the demand would change concerning variants or volumes it might be necessary to start performing these changes of fixtures but in the current situation there are none.

In order to further analyze the validity of the machining, concerning carriers, the maximum production of one day were compared. The differences between model and reality were smaller but still greater than ±2%. Since the maximum amount of carriers machined by one single Heller machine in reality is 124, any variation in the models output will generate a large difference in percent. The results were also tested on operators and engineers in order to further ensure validity with good results.

Even though large effort were put into ensuring validity for the model there are questions regarding the validity of results generated by the model. To eliminate these questions sensitivity analysis were conducted in order to reduce the theoretical output from machining and thus ensuring the validity of the results.

When performing the sensitivity analysis it was found that input concerning cycle times for machining of carriers is most significant for the output. The sensitivity analysis concerning unknown cycle times showed that it is possible to increase the cycle times with as much as 45% before runs with faults were detected. 45% is considered a significant increase and shows that the effects of the input data are low. The input data gathering concerning set up and tool change were also estimated which raises questions about the validity. When including these parameters as well as the cycle time it is shown that an increase of 25% is possible which also should be considered sufficient. The sensitivity analysis also evaluated the effect of set up and changes of tools parameters separately. The analysis showed 35% increase without problems. With these results it is shown that there can be significant errors concerning input to machining of carrier without any effect on the final results of this project.

7 Recommendations

- Implement scenario daily production for carrier and scenario daily replenishment for materials not machined in-house.

- Unavailable data has made it difficult to model and validate machining in the project. OEE measurements, Cycle times, setup times, time for exchange of tools, maintenance and working procedures etc. should be properly investigated and documented. This in order to enable problems to reach the surface and set a foundation for continuous improvements (Liker 2004). Also errors, stops and break downs should be logged at all occasions. Standardized work concerning setups should be elaborated in order to enable future improvements with reducing setup times.

- Problems with machining should not be hidden under huge inventories and long lead times. The Company should not be afraid of shortening lead time and reduce buffers radically even if it will cause problems. Then the company will be forced to take actions of these matters and gain opportunities to develop and improve (Liker 2004).

- Future shapes of carriers should be designed for machining enabling them to be processed without the need for setups which will increase flexibility.

8 Conclusions

Q1 The daily production scenario for carrier requires only 45 pallet slots at assembly and 45 at machining resulting in reduction of 100 pallet slots compared to the current situation. The daily replenishment scenario for material not machined in-house will require only 53 pallet slots compared to current 86. Implementation of the both scenarios will result in a total reduction of 48 %.

Q2 The critical parameters that affects the required space in production are has been identified as:

Production planning:
The configuration of the production planning concerning mainly the release time.

Amount of variants:
How many variants that are present for each specific part.

Overproduction of carriers:
Overproduction of carriers in order to achieve 28 parts in each pallet.

Dedication of pallets slots:
Dedicating pallet slots for a special variant of a part.

Truck frequency:
How often the trucks are allowed to transport parts between machining, central storage and the assembly.

Resilience of machining and pre-assembly:
How resilient the system is concerning up-time and production rate.

MQ In order to cope with all the variants and keep the need of space a new way of categorizing carriers could be implemented. Instead of sorting carriers of what kind of carrier they are, they can be sorted according to when they are going to be assembled. A similar way of thinking can be applied also to other materials than carriers. The most radical differences compared to current state will require the machining processes to be improved in order to enable fewer carriers than 28 to be processed at a time. This has been a basis for enabling future improvements when reducing production space. Also the production planning will be changed and be based on actual demand instead of forecasting. This will reduce the risk of overproduction and avoid unnecessary inventory occupying valuable space.

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Appendix A – Conceptual Model

General

- Arrows shows the flow of material without concern for physical transportation.
- Only carrier, crossbar and lever are included as material. Ther are of course other material as well.
- The orders are set on a weekly basis and are introduced to the Okline.
- CF handles the tranportation of goods if not stated otherwise.
- There are three variants of the machanism and three main variants of the brakes (22tum, 22tumLT samt 19tum)
- Production planning for machining is made two weeks prior to the actual order. It is done manually. Production orders are allways in whole box pallets.

Okline

- Planning of production is made according to orders on a weekly basis
- Setuptime at the Okline is determined by the transportation of material by forklifts. Stn 1,2,4, 9 and packaging changes material by forklift when the production changes
- Transportation of material connected to the Okline is performed by the operators themselves
- There are enough operators to handle the stations and transportation
- The buffer size differs between 3-6 pallettes for different stations
- There are 25 palettes total
- 270 units/shift

Mekline

- Initiates by a kanban call from assembly or order to china
- Produces 3 different Mechanism, with spring, with puck, or neither.
- Automated process assembling caps before stn 1
- Products are pulled from the automated assembly
- Stn 2 consist of a machine that are fed by an operator, the operator can prepare a product while machine is running
- Deviation on stn 2, normally 2-3 per week causing a loss of time for approx 30 sec each time
- Mechanism are packed for shipping to China or put into kanban bin of 30 units
- Operator move Mechanism to Loctite when bin full
- 7 kanban pallets for without spring, 5 with spring and 3 with puck
- 4 operators
- Capacity 340 units/shift

Loctite

- Production planning depends on the product orders. "Common sense"
- Assembled products are put into storage for drying. Some are sold and some are fed into the system.
- The time for drying is approximately 1 hour
- Three variants on Calliper housing, which are depending on geometry. 3 different for 19inches, 3 for 22 and 2 for 22LT

Machining Lever

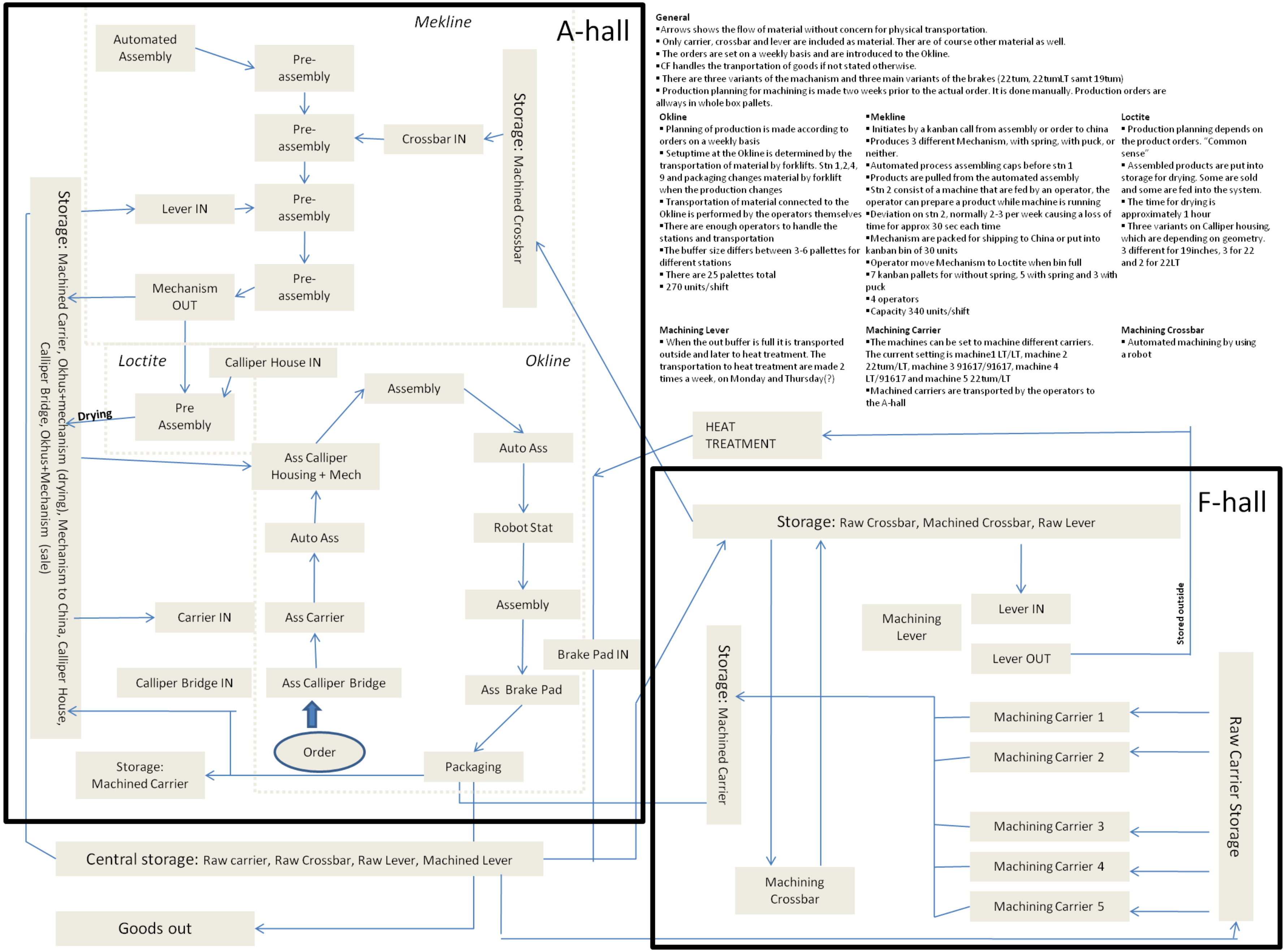
- When the out buffer is full it is transported outside and later to heat treatment. The transportation to heat treatment are made 2 times a week, on Monday and Thursday(?)

Machining Carrier

- The machines can be set to machine different carriers. The current setting is machine1 LT/LT, machine 2 22tum/LT, machine 3 91617/91617, machine 4 LT/91617 and machine 5 22tum/LT
- Machined carriers are transported by the operators to the A-hall

Machining Crossbar

- Automated machining by using a robot



Appendix B – Distribution of carriers per week

Table 15 – Number of carriers per week

Carrier	Average	Max	1	2	3	4	5	6	7	8
90782	153	414	255	39	0	24	192	28	122	414
91062	138	462	104	78	462	110	192	0	6	16
91072	77	224	224	0	0	37	60	24	38	80
91617	687	916	686	867	757	549	531	450	916	743

Table 16 - Number of pallets per week

Carrier	Average	Max	1	2	3	4	5	6	7	8
90782	5	15	9	1	0	1	7	1	4	15
91062	5	17	4	3	17	4	7	0	0	1
91072	3	8	8	0	0	1	2	1	1	3
91617	25	33	25	31	27	20	19	16	33	27

Table 17 - Usage of overflow slots per carrier and week, scenario reducing dedication variant A

Carrier	Size of warehouse	1	2	3	4	5	6	7	8
90782	2,0	8	0	0	0	5	0	3	13
91062	4,0	0	0	13	0	3	0	0	0
91072	2,0	6	0	0	0	1	0	0	1
91617	26,0	0	5	2	0	0	0	7	1
Overflow		14	5	15	0	9	0	10	15

Max simultaneous utilized overflow is 15

Appendix C – Input data

Table 18 - Machining carrier

Carrier	Cycle time in machine (two carriers)
90782	728
91062	851
91617	977
92818	1074
92828	779
Other carriers	estimated to 2*triangular top(485,390,540) s
Robot (Seconds per carrier)	
Loading	30,6
Unloading	70,8
Setup new raw material	triangular top (25,20,30) minutes
Stop time counting 24/7*	
Tool change frequency machine 4 and 5	Estimated Triangulartop(120,100,140) minutes
Tool change frequency machine 6**	Estimated Triangulartop(110,80,140) minutes
Duration	Estimated Triangulartop(4,3,6) s

**Counting 24/7 was an easier way to implement in the model compared to counting active time.*
*** Machine 6 were infected by an unexplained error that caused the machine to stop approximately once a week which was compensated by increasing frequency of tool change.*

Table 19 - Machining lever and crossbar

	Lever	Crossbar
Cycle time	720	504
Loading/unloading	Triangulartop(80,60,100)	Triangulartop(10,0,60)
Change of tools ver 1	Triangulartop(120,60,240)	
Change of tools ver 2	Triangulartop(120,60,240)	mins(20)
Change of tools ver 3	Triangulartop(40,32, 48) minutes	
Mean time to failure	Triangulartop(4368,3500,5000) hours	Lognormal(1361.45,1107.19) minutes
Mean time to repair	Triangulartop(600,480,900) minutes	Negexp(63.64) minutes

Change of tools ver 1 occurs every 5000 parts that has been machined. Change of tools ver2 and ver3 occurs once per shift.

Table 20 - Input data for assembly

	Cycle time		Set ups		
Station	**Long**	**Short**	**Set up station**	**New order**	**New material**
1	Triangulartop (42.8,37.0,50.5)			Triangulartop (25,20,30)	Triangulartop (90,80,100)
2	Triangulartop (27.4,22.9,37.9)			Triangulartop (25,20,30)	Triangulartop (90,80,100)
3	Triangulartop (32.6,32.2,33.4)				
4	+(44.00,Logistic (17.30,7.87))			Triangulartop (25,20,30)	Triangulartop (20,18,25)
5	+(71.00,Beta (11.20,0.50,1.10))	Triangulartop (47.8,43,52)	Triangulartop (100,80,120)	Triangulartop (25,20,30)	
6	Triangulartop (30.7,30.6,30.9)				
7	Triangulartop (64.1,61.6,67.2)		Triangulartop (90,80,110)		
8	Triangulartop (57.7,52.6,61.7)				
9	+(57.00,Gamma (16.79,7.40))	Triangulartop (32,27,49)		Triangulartop (25,20,30)	Triangulartop (90,80,100)
10	Logistic (65.71,5.42)	Triangulartop (32.8,30,40)		Triangulartop (25,20,30)	Triangulartop (20,18,25)

Table 21 - Input data for pre-assembly

	Cycle time	**Mean time to failure (minutes)**	**Mean time to repair (minutes)**
Stn 1	Logistic(44.1,9.9)	Triangulartop(3740,340,8160)	Triangulartop(80.9,15,216)
Stn 2	Normal(38.00,9.22)		
Stn 2b	Lognormal(60.00,10.59)		
Stn 3	Lognormal(38.40,11.50)		
Stn 4	Weibull(30.47,4.20)	Triangulartop(2890,1700,4760)	Triangulartop(40,20,60)

Loctite

Station	**Cycle time**	**Loading**	**Unloading**
LOC automatic	50	Triangulartop(30,20,40)	
LOC manual	Triangular(39.7,33,47)	Logistic(28.77,9.64)	Triangular(10.4,8,12)

Table 22 - Packaging instructions

Time to pack one package	Triangulartop (180,160,200) s
Order number	**Products in package**
89970	9
92240	9
92245	9
92246	9
92249	8
92250	8
92253	9
92254	9
92257	8
92258	8
92259	8
92260	8
92502	10
92503	10
92559	10
92560	10
92612	8
92774	16
92776	16
92802	10
92803	12
92812	12
92824	10
92844	16
92927	12
93055	10
93334	10
93694	4
93695	4
93696	4
93697	4
93698	16
93835	10
93836	10
93837	10
93839	10
93840	10
93841	10
93842	12
93963	16
94027	8
94478	8
94605	4
94795	10
94830	9
94850	8
94918	10
Others	Assumed to be 9 or matched to order size

Appendix D – Time study

Task	Expected variation	Expected effect	Estimated cycle time (sec)	Number of samples	Estimated time
Loading Heller machine through robot (Carrier)	High	High	60	30	1800
Cycle time, Heller (Carrier) (23 different variants)	Low	High	500	23-69	15000
Unloading Heller machine through robot (Carrier)	High	High	60	30	1800
Loading Heller machine manually (Lever)	High	Low	30	6	180
Unloading Heller machine manually (Lever)	High	Low	30	6	180
Pre-assembly station 1 (EPT)	High	High	60	30	1800
Pre-assembly station 2 (EPT)	High	High	60	30	1800
Pre-assembly station 2b (EPT) (Balancing)	High	High	60	30	1800
Pre-assembly station 3 (EPT)	High	High	60	30	1800
Pre-assembly station 4 (EPT)	High	High	60	30	1800
Loctite manual assembly (EPT)	High	High	30	60	1800
Loctite automated assembly (EPT)	Low	High	30	3	90
Assembly station 1 (EPT)	High	Low	30	6	180
Assembly station 2 (EPT)	High	Low	30	6	180
Assembly station 3 (EPT)	Low	Low	30	3	90
Assembly station 4 (EPT)	High	High	60	30	1800
Assembly station 5 (EPT) (two different variants)	Low	Low	30	6	180
Assembly station 6 (EPT)	Low	Low	30	3	90
Assembly station 8 (EPT)	High	Low	60	6	360
Assembly station 9 (EPT) (two different variants)	High	Low	60	20	1200
Assembly station 10 (EPT) (two different variants)	High	Low	60	20	1200

Appendix E – Validation

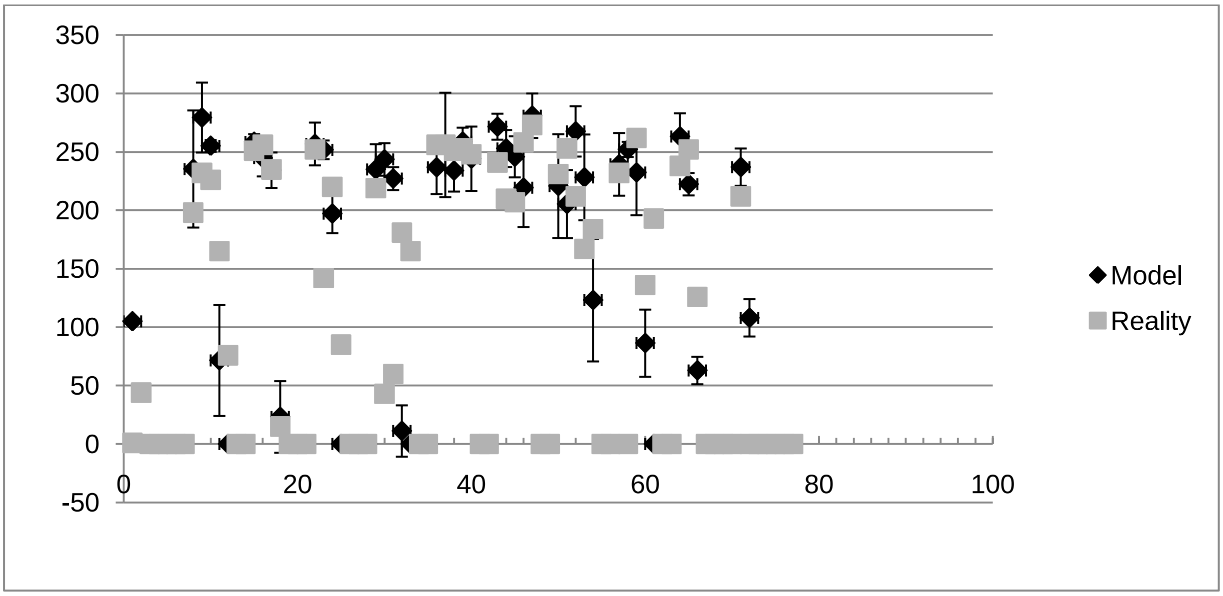


Figure 8 - Validation of assembly on a daily basis. This graph was used in order to ensure that the daily variations were small enough.

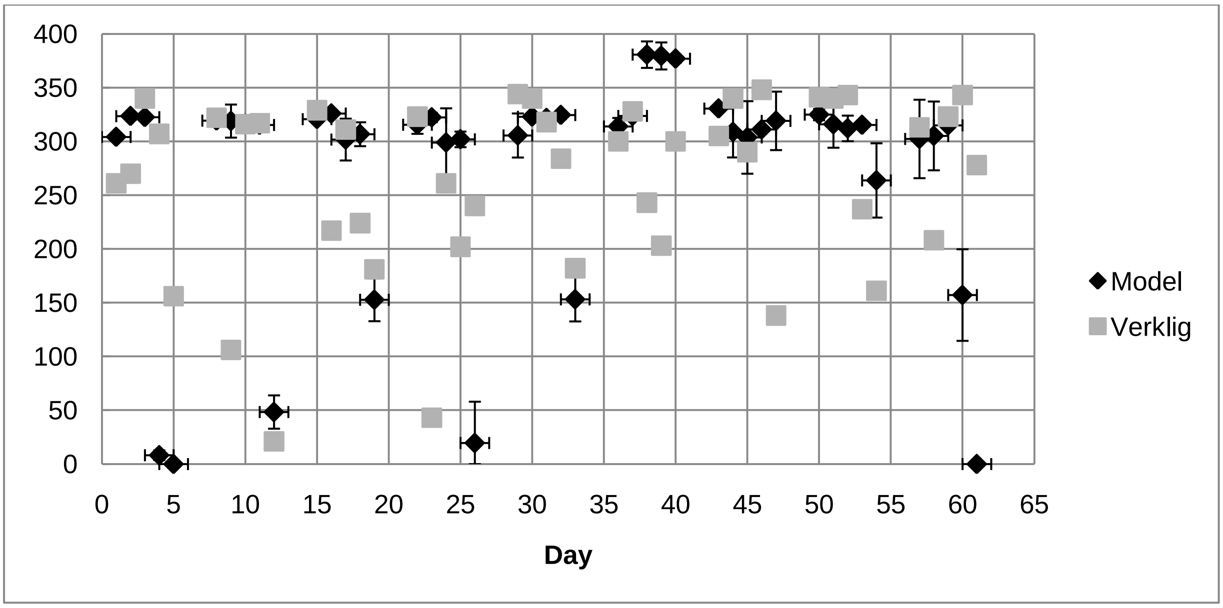


Figure 9 - Validation of pre-assembly on a daily basis. This graph was used in order to ensure that the daily variations were small enough.